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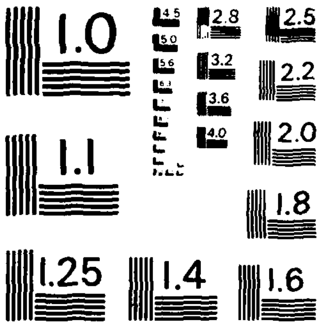

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U.S. Department of Transportation
Federal Aviation Administration

Response to Congressional Recommendations Regarding the FAA's En Route Air Traffic Control Computer System

DOT/FAA/AAP-82-3

January 1982

Report of
the Federal Aviation Adminstration
to the Senate and House Appropriation Committees
pursuant to S. Report 96-932
on the Department of Transportation and Related Agencies Appropriation Bill for FY 1981

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20591

OFFICE OF
THE ADMINISTRATOR

FEB 16 1982

The Honorable Mark Andrews, Chairman
Subcommittee on Transportation
Appropriations Committee
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

During the last few months, the Federal Aviation Administration (FAA) has provided your committee full responses to Recommendations 4, 5, 6, and 7 and interim responses to Recommendations 1, 2, and 8 of the Conference Report on the Department of Transportation and Related Agencies Appropriation Act, 1981, regarding the FAA's en route air traffic control computer system.

In providing the interim responses, I informed you that the delays experienced in responding to your recommendations were due, in part, to my ongoing review of key FAA programs including the En Route Advanced Computer Program.

This submittal contains the responses to all of the recommendations. Also included are the three major analysis study reports as Appendices. The FAA's recently completed "National Airspace System Plan" includes the long range planning for the Advanced Computer Program. This plan is submitted in response to your Recommendation 3.

It should be noted that the specific options that were analyzed reflect the concerns identified in the Congressional Recommendations. As such, no single option includes the selected approach which is a composite of the options and variations of the options. Additional documentation will be provided to you as further analyses and definition of the selected approach are finalized.

I trust that this report provides all of the responses to your recommendations.

Sincerely,

J. Lynn Helms
Administrator

Enclosure

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20591

OFFICE OF
THE ADMINISTRATOR

FEB 16 1982

The Honorable Adam Benjamin, Jr., Chairman
Subcommittee on Transportation
Committee on Appropriations
House of Representatives
Washington, D.C. 20515

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Enclosure

List of Enclosures

Summary of Responses to Conference Committee Recommendations

Response to Conference Committee Recommendations

Appendices

1. Meeting En Route Air Traffic Control Requirements in the 1980's and 1990's - An Option Analysis, Report

2. Operational Delay Day Forecasts for the Twenty Air Route Traffic Control Centers for the Years 1982 through 2011, Report

3. An Economic Analysis of Investment Options to Replace the En Route Center Computer System - A Quantitative Assessment of Benefits and Costs; Report

National Airspace System Plan

SUMMARY OF RESPONSES TO

CONFERENCE COMMITTEE

RECOMMENDATIONS

Senate Recommendations

Recommendation

Recommendation 1. "No Research, Engineering, and Development funding for fiscal year 1981 be expended for the proposed replacement system pending completion of a comprehensive study and analysis by FAA to determine: Capacity and current and anticipated deficiencies of the existing system; cost estimates of a replacement system to correct such deficiencies, be adequate to meet current and future needs, insure continuous safe separation of aircraft, and require minimum funding resources; best estimates and full disclosure of the required present and proposed future tasks offered as justification of the replacement system; nonessential tasks or functions which could be permanently shed from the current and replacement systems; interim actions and funding necessary to correct identified deficiencies and enhance the current system in order to extend its operational life during the replacement system acquisition cycle."

Recommendation 2. "The FAA comprehensively evaluate and determine as a short range alternative to en masse replacement of the current system, the feasibility, cost/benefits and funding requirements of buying or leasing computers for centers determined to exceed capacity in the 1980's, and of functionally splitting and upgrading the software."

Recommendation 3. "The FAA develop a comprehensive, formal, long-range plan to reflect agency strategies, goals, and objectives and be reviewed and approved by top management. The plan should set forth milestones for measuring and controlling activities, funding requirements, achieving efficient and effective use of resources and committing top management to action."

Recommendation 4. "The FAA develop a statement of goals for measuring overall efficiency of the current computer system including processing requirements for general overhead and recording functions with accompanying plan and implementation schedule."

Recommendation 5. "The FAA establish a computer performance management function to systematically evaluate the capacity and performance of their computer systems. Staffing needs and costs for this function should be identified and reported to the committee for consideration."

Recommendation 6. "The reporting criteria of one minute or more for reporting an outage be dropped and all outages of any duration be recorded so as to determine their impact on safety, service to user, and computer performance reliability."

Recommendation 7. "The FAA revise its reporting system to eliminate the practice of reporting unscheduled maintenance outages as scheduled outages. Scheduled maintenance should cover only regular,

periodic, routine preventive maintenance tasks. Reporting unscheduled outages as scheduled distorts recording of corrective maintenance actions and computer performance reporting."

Recommendation 8. "The FAA should give top priority to developing an adequate backup capability for the current en route computer system. This should include determining effective and economical alternatives to sole source spending of an additional $38 million to upgrade the direct access radar channel. Consideration of alternatives should include offloading the radar processing from the current system to peripheral computers which would serve as primary and backup thereby extending the life of the current system or an interim replacement system."

SUMMARY OF RESPONSES

RECOMMENDATIONS	RESPONSE
1	a. Capacity of the existing system, as a result of ongoing FAA improvements, is adequate to meet all anticipated requirements through the mid 1980's. b. Current and anticipated deficiencies of the existing system are projected to introduce constraints on traffic growth, constraints on the addition of new functions and interfaces, increased software and maintenance costs, and increasing difficulty in acquisition of spare parts. Automation of additional ATC functions is needed in the late 1980's to provide increased effectiveness and productivity in the ATC system. c. Preliminary cost estimates to meet short-range requirements and insure continuous safe separation of aircraft through the 1980's range from \$96M to \$240M (1981 \$) for various interim options or software rehosting on new computers. d. Replacement system costs, including near term capacity solutions and construction, are projected at \$1.6B (1981 \$). Present and proposed automated functions can be accommodated by the Advanced Computer System. e. No nonessential tasks or functions, which could be permanently shed from the current and replacement systems, have been identified at this time. Candidate items for offloading include selective recording and training functions. f. A total of \$10M will have been expended through FY 82 to complete current FAA initiatives directed to correct deficiencies and enhance the current system to extend its operational life through the mid 1980's. These funds are currently appropriated and allocated within the FAA's budget.
2	• FAA has already undertaken short range measures to enhance system performance with the existing computer hardware and software (see Recommendation Responses 1a and 1f above). These actions must be supplemented by rehosting software on the new computer to satisfy projected capacity requirements through the 1980's (see Recommendation Response 1c above).
3	• An approach to meeting near and far term en route computer requirements has been selected as a result of the analysis conducted in response to Recommendation 1. This approach has been formalized in conjunction will all other major capitalization programs and is described in the National Airspace System Plan. This plan shows the evolution of all FAA systems through the year 2000. It contains objectives, strategies, subsystem descriptions, and estimated schedules.
4	• A baseline system has been established and measured. Goals for efficiency measurement have been defined, and procedures have been instituted to evaluate performance against these goals.
5	• Organizational changes establishing a performance management program have been initiated. Management guides and directives have been produced and will be put into effect.
6	• All en route computer interruptions, regardless of length, will be uniformly reported by the National Airspace Performance Reporting System which was implemented in January 1982.
7	• Maintenance interruptions are redefined to clearly delineate categories. Implementation of reporting changes will be accomplished as noted in #6, above.
8	• Alternative approaches to providing system backup capability have been evaluated. DARC is indicated as having the lowest cost, shortest schedule and least risk.

RESPONSES TO CONFERENCE COMMITTEE'S RECOMMENDATIONS

Recommendation 1. "No Research, Engineering and Development funding for fiscal year 1981 be expended for the proposed replacement system pending completion of a comprehensive study and analysis by FAA to determine: Capacity, and current and anticipated deficiencies of the existing system; cost estimates of a replacement system to correct such deficiencies be adequate to meet current and future needs, insure continuous safe separation of aircraft and require minimum funding resources; best estimates and full disclosure of the required present and proposed future tasks offered as justification of the replacement system; nonessential tasks or functions which could be permanently shed from the current and replacement systems; interim actions and funding necessary to correct identified deficiencies and enhance the current system in order to extend its operational life during the replacement system acquisition cycle."

FAA Action: FAA's response to Recommendation 1 follows:

1.0 Introduction

FAA projections show that the air traffic control operating environment will change significantly over the next two decades. These changes include continuing increases in the traffic volume and technological improvements in the surveillance, communication, and navigation systems that support air traffic control (ATC). There will be changes in the aircraft fleet mix, in aircraft equipment, and in aircraft flight patterns. ATC functional improvements and new services will be required to accommodate these changes. Higher levels of ATC automation will be required to accommodate traffic growth in some areas where the traditional technique of reducing sector size to handle higher traffic levels will no longer work because sectors have already been reduced to the minimum effective size for air traffic control. Greater automation will also be required to increase the productivity of the controller workforce and to permit more fuel-efficient aircraft operation.

FAA today operates the largest real time automated air traffic control system in the world. At the core of that system is a highly reliable en route computer system composed of hardware, software, and controller stations (sector suites).

Studies have shown that the current 9020 computer system will not have the capacity to accommodate increasing traffic demand and changes in the aviation environment in the forecast period. In addition, there have been significant advances in computer technology beyond those incorporated in the present 1960's technology system. These advances in both hardware and software technology can provide significant improvements in system maintainability and reliability, cost versus performance, and system capacity.

FAA has carried out a comprehensive study and analysis with the specific objectives of determining the effectiveness of continuing to operate the present en route system and of identifying a plan for orderly upgrade or replacement of that system in light of the above considerations. The following sections provide a summary of this analysis and its conclusions in response to Recommendation 1.

2.0 Analysis and Findings

2.1 Approach

The general approach to this analysis was to identify the requirements for en route ATC through the turn of the century, to assess the ability of the existing system to meet these requirements in the current (1981-85), near term (1985-1990) and far term (1990-2000) time periods, to postulate alternatives that build on or replace the existing system, and to evaluate the suitability of these alternatives (options) for the near and far term. Specific activities for this study were data collection, data analysis, and alternative definition, evaluation, and selection.

2.2 DATA Collection

The FAA simultaneously collected data regarding proje ed environmental changes, projected technological change and present system baseline definition.

2.2.1 Forecasting Environmental Changes

The FAA forecasted air traffic on a center-by-center basis over the period of 1981-2011.

All affected organizations were contacted to obtain their projected needs. The system's users, including system operations, provided input through the FAA New Engineering Development and Initiatives activity*. Future functional improvements were identified by FAA far term planning activities. Operational requirements and maintenance requirements were provided by the FAA operational services, the Air Traffic Service and the Airway Facilities Service.

2.2.2 Evaluating Technological Changes

Projected technological changes were surveyed in those areas which would support further improvement of the air traffic control automation system. Advances in computer and display hardware were examined. Specific aspects of this survey addressed both component advances and architectural advances.

In addition to functional and capability advances, the survey also examined new techniques for increasing reliability, maintainability, and availability.

The impact of technology on the cost per unit of hardware as compared with the capability per unit of hardware was also examined. In the area of software, advances in engineering methods and techniques were studied. Product and process standardization and gains to be obtained were examined.

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*Federal Aviation Administration, New Engineering and Development Initiatives - Policy and Technology Choices, Consensus Views of User/Aviation Industry Representatives, Washington, D.C., March 1, 1979.

The impact of software engineering techniques on reliability and maintainability was studied. Cost versus capability improvement was also the subject of analysis.

2.2.3 Defining Present System Baseline

In order to determine the ability of the present system to cope with anticipated changes, the FAA defined a baseline for the present system including all hardware, software, and display components. Present system operational functions were categorized and documented in a baseline system description. The functions were analyzed and candidates for modification or elimination were identified. The functional specifications were then rewritten to address generic requirements rather than design solutions.*

For each of these functions and for the system as a whole, various studies were conducted to define capacity, reliability, maintainability, and productivity characteristics. Capacity characteristics address the capability of the systems and its components to handle specific volumes of workload within specific periods of time. Reliability characteristics address the ability of the system and its components to provide services at a specific points in time. Maintainability characteristics involve the ease with which system deficiencies can be corrected and the system can incorporate improved functional capabilities. Productivity characteristics treat total system productivity and its components parts. These include both user operating efficiency and FAA effectiveness and productivity with respect to facilities, equipment, and personnel utilization.

A detailed analysis of the 9020 software structure was conducted to determine software maintainability characteristics. Specific emphasis was placed on an assessment of the suitability of the existing software as a base for the addition of new functions. A second analysis examined the potential capacity buy back of the FAA's ongoing sustaining engineering initiatives.

2.3 Data Analysis

Having collected data regarding the present state of the system and the future environment in which the system must operate, FAA conducted analyses to determine whether or not specific limitations would exist. These analyses identified needed improvements in three distinct time frames: the current (1981-1985); the near term (1985-1990); and the far term (1990-2000).

2.3.1 Present Limitations

It was found that without the buy back of sustaining engineering initiatives, a few en route centers would experience air traffic

*(System Level Specification, En Route ATC Automation System, FAA-ER-130-003).

delay due to lack of capacity to accommodate forecast traffic loads before 1985. These estimates assumed that none of the functional automation improvements ready for implementation in this time period would be added to the system. See Appendix 2 (Operational Delay Day Forecasts for the Twenty Air Route Traffic Control Centers for the years 1982 through 2011).

System outage reports indicate that system and component reliability and maintainability need improvement. The degree to which this can be achieved in the current system is limited by the 9020 architecture and 1960's technology. In addition, capacity and software limitation preclude delivery of major potential productivity gains, which could possibly accrue from (1) facility consolidation, (2) the automation of controller-performed functions, and (3) the addition of new ATC services that would allow the aviation user to operate in a more cost-effective manner. Facility consolidation is currently being studied as a major input to the Advanced Automation Program planning. The constraints identified in the near term performance of the current system will become more severe as additional aircraft demand for services develops.

2.3.2 Future Opportunities

Technology advances should alleviate some of the limitations identified as existing in the present and compounded in the future. Hardware performance versus cost is an area of potential improvement. Hardware reliability has and will continue to improve. Software engineering and software productivity has and will continue to improve. Better, more reliable software can be developed and maintained at a lower cost than in the past.

2.3.3 Overcoming Present Limitations

FAA has underway a number of sustaining engineering initiatives aimed at overcoming present limitations. These consist of improvements to the current hardware and software for the purpose of capacity buyback. These efforts will extend the performance capability of the present system enough to meet projected traffic growth through the mid-1980's. They will not significantly increase the reliability or productivity of the present system, nor will they support implementation of additional automation functions. Total cost of these improvements is approximately $10M and implementation will be completed in 1982.

2.3.4 Near Term and Far Term Limitations

The analysis showed that the present limitations were capacity-related, but were of a magnitude small enough to be overcome by sustaining engineering activities. The near term needs were also dominated by capacity deficiencies which, however, exceeded the added capacity provided by the sustaining engineering activities. The far term needs are related to meeting forecast increases in air traffic, accommodating functional evolution to accommodate the projected environmental changes and higher levels of ATC automation, improving reliability, and constraining maintenance cost growth. In the far term, a major requirement exists for improving the productivity and efficiency of the ATC system.

2.4.0 Alternative Solutions to Meet Needs Beyond 1985

A variety of alternative solutions (options) for improving the ATC system and meeting the near term (1985-1990) and far term (1990-2000) requirements have been defined and analyzed. The analysis showed that full system replacement (hardware, software, and sector suite) would be required to meet the far term needs. Several of the options addressed such full replacement. Neither design, development, and testing of new software nor sector suite development can be completed before the late 1980's, therefore, some capacity solution short of full system replacement is required to meet near term needs. Several options were defined to meet near term needs. Because they do not involve full system replacement, they do not meet the far term requirements.

The options were selected to cover a spectrum of alternatives for meeting FAA's mission and encompass all of the alternatives suggested in the Senate Appropriation Committee recommendations. Each option is a representative example of a broader category of solutions. The initial option analysis (documented in Appendix 1) was performed with the full expectation that the approach ultimately selected for meeting FAA's automation requirements would very likely be a variation of one or combination of several options. The options were evaluated in terms of cost, schedule, benefits, technical feasibility, transition impact, and risk.

Near term solutions fall into the categories of 9020 augmentation and full 9020 hardware replacement. Far term solutions can either build on near term hardware replacement or be based on a totally new system design. In the latter case, one of the 9020 augmentation alternatives is required to meet near term needs. An options analysis tree in Figure 1-1 indicates a logical sequence of events relating the various alternatives.

2.4.1 9020 Augmentation

9020 augmentation retains the present hardware and software and extends its capability by adding or replacing hardware components and, in some cases, off loading software from the 9020 computer elements to achieve performance improvement. Three such options were examined:

- o Off load functions to an external processing system (Prime Channel DARC)
- o Extend the computational capability of the 9020 input/output processors and off load software to these units (IOCE Replacement)
- o Replace 9020A computer elements with more powerful 9020D's computer elements

This solution category would provide sufficient capability improvement to meet projected near term requirements. Productivity gains would be limited to those available from an electronic tabular display capability in the sector suite.

Hardware maintainability gains resulting from more current technology are more than offset by more complexity in software

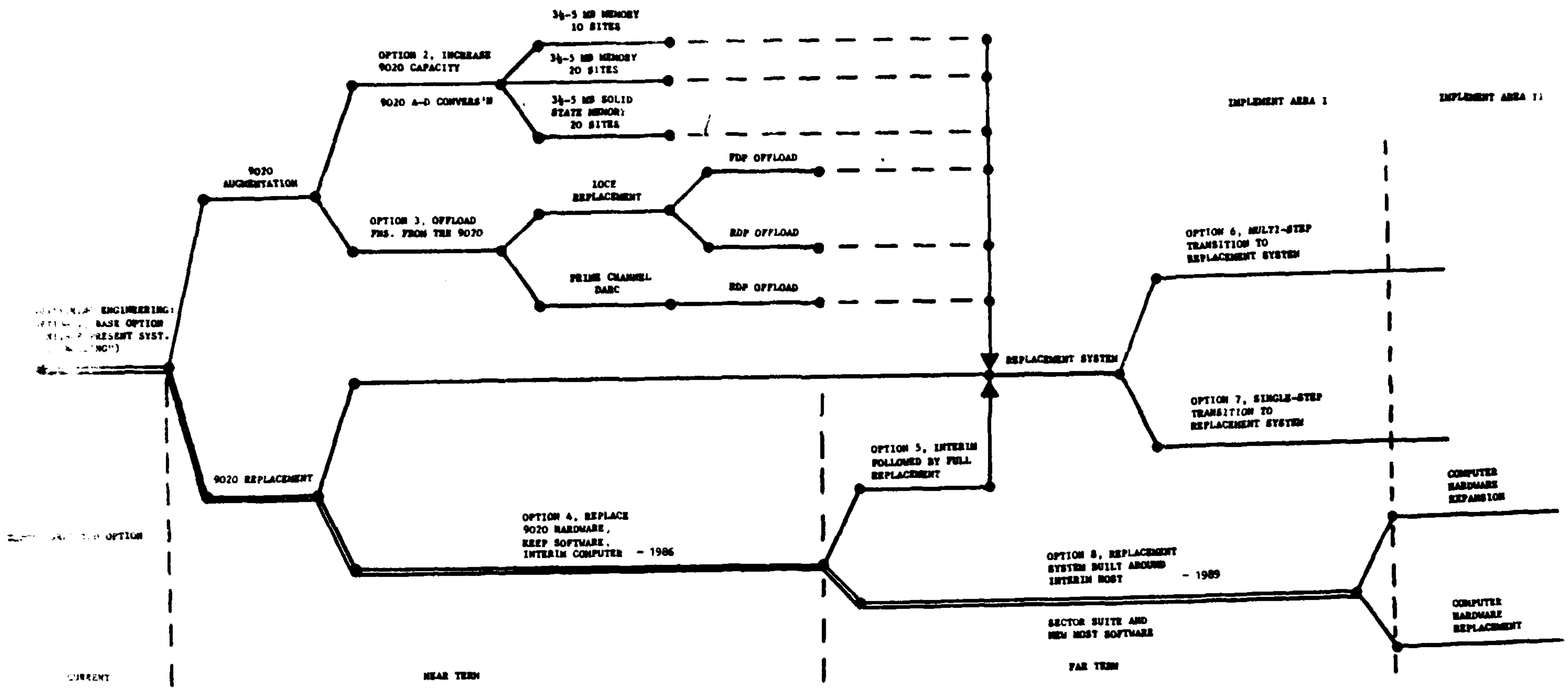

FIGURE 1-1, OPTIONS ANALYSIS TREE
(LOGICAL SEQUENCE OF EVENTS)

maintenance in the first two cases. The conversion of the 9020A to a 9020D would provide a minimum risk approach to upgrading the system. However, use of 1960 vintage hardware would not improve system reliability or reduce maintenance costs. Cost and schedule estimates are shown in Figure 1-2.

2.4.2 Hardware Replacement

This category entails replacing the 9020 hardware with a more powerful, current generation computer system that can host the 9020 software to achieve performance enhancement. The existing 9020 software would be adapted to run on this new "host" computer. Such a host computer can be augmented (with new software and sector suites) to meet far term needs.

A new host could provide capacity to the turn of the century and beyond, but the existing software would limit addition of major new functions. Reliability and maintainability would be enhanced since the 9020 is replaced with state-of-the-art hardware. As a result of performance gains, the productivity improvements obtainable with electronic tabular display capability in the sector suite could be achieved. This option represents an acceptable risk approach which can be carried out in time to meet FAA's near term objectives. Cost and schedule estimates are shown in Figure 1-2.

2.4.3 Far Term Host Augmentation

A host for near term capacity needs offers the opportunity to add new sector suites and to replace the 9020 software so that far term requirements could be met. This alternative has the benefit that no 9020 augmentation is required to meet near term capacity needs. Figure 1-2 provides an evaluation summary of this option.

An alternative course of action would be to defer a full replacement program for several years and replace the host with a total new system when it is ready. While included in the analysis of Appendix 1, this alternative is not considered here since it would postpone implementation of the system needed to meet FAA's far term needs.

2.4.4 Full System Replacement

This category of options involves total hardware/software redesign and subsequent replacement of the hardware, software and sector suites. The hardware/software replacement could be done in a single step or in multiple steps. A two-step replacement (Radar processing followed by flight data processing) was evaluated as representative of a multi-step replacement of the 9020. Figure 1-2 summarizes the analysis of these two alternatives.

In considering the full system replacement, the one step replacement is the preferred alternative. Multi-step replacement of a large system has been suggested as a means of lowering the risk associated with development of large complex systems. The analysis of the two-step replacement showed that because of the structure and complexity of the 9020 software, the design of the replacement system would be compromised. Furthermore, replacing only part of the 9020 would not eliminate the need for near term capacity

		PERFORMANCE/ CAPACITY YEAR OF OPERATIONAL DELAY DAY OCCURENCE	RELIABILITY/ AVAILABILITY	MAINTAINABILITY/ HARDWARE	COST (1981 $)	TECHNICAL RISK	SCHEDULE (YEAR OF FIRST SYSTEM OPERATIONAL)
NEAR TERM OPTIONS	HARDWARE AUGMENTATION						
	o IOCE OFFLOAD (3a)	1991	MINIMAL IMPROVEMENT	FAIR-GOOD	$123.6M	MED	1985
	o PRIME CHANNEL DARC (3b)	1990	SMALL * IMPROVEMENT	GOOD	$ 45. M	MED	1986
	o 9020 A - D CONVERSION (2)	1996-98	NO CHANGE	NO CHANGE	$ 32/64M	LOW	1984
	HARDWARE REPLACEMENT						
	o HOST (4)	AFTER 2000	MED IMPROVEMENT	EXCELLENT	$226-252M	LOW-MED	1986
FAR TERM OPTIONS	HARDWARE AUGMENTATION						
	o HOST AUGMENTATION (8)	NOT APPLICABLE	EXCELLENT**	EXCELLENT	$1.4B-1.5B(a)	MED	1990
	HARDWARE REPLACEMENT (FULL REPLACEMENT)						
	o SINGLE STEP (7)	NOT APPLICABLE	EXCELLENT	EXCELLENT	$1.3B-1.5B(b)	MED	1989
	o TWO STEP (6)	NOT APPLICABLE	EXCELLENT***	EXCELLENT	$1.4B(b)	HIGH	Step 1 - 1989 Step 2 - 1991

* LOSS OF BACKUP CHANNEL OFFSETS THIS
** REQUIRES REPLACEMENT/UPGRADING OF HOST TO MEET ACS REQUIREMENTS
*** AFTER STEP 2
a INCLUDES INTERIM COMPUTER
b REQUIRES NEAR TERM OPTION

NOTE: These options reflect the concerns identified in the Congressional Recommendations. As such, no single option includes the selected approach which is a composite of options and variations of options.

FIGURE 1-2, OPTIONS EVALUATION SUMMARY

augmentation even though the new RDP system could be available a little earlier than a complete one-step replacement system.

3.0 Findings

The FAA Administrator has, on the basis of this study and the attached National Airspace System Plan, selected a course of action that will meet the aviation system requirements and overcome any potential limitations of the en route system. It should be noted that the specific options that were analyzed reflect the concerns identified in the Congressional Recommendations. As such, no single option includes the selected approach which is a composite of options and variations of options. That course of action is summarized by the following steps.

(1) Complete the current FAA sustaining engineering activities.

(2) Rehost the 9020 software in a modern highly reliable computer. The hosting alternative selected is more limited (no display channel replacement) than that considered in the option analysis. This choice will provide capacity enhancement in 1986 with minimal schedule risk.

(3) Simultaneously a system development and implementation activity to provide a replacement system that uses the host hardware as an element of the future system. This system will include the hardware and software capabilities set forth below.

(a) Replace the current sector suites and display channel with a new sector suite. The sector suite will be designed for use in the en route and terminal environments. The first en route sector suites will become operational in the 1987/1988 time frame.

(b) Develop totally new software for the host computers that provides current, near term, and initial advanced automation functions (denoted as AERA-1 in Figure 1-1). This software will be designed for use in both en route and terminal environment. New software will become operational at en route centers in the 1989/1990 time frame.

(c) Evolution of this system in the 1990's to accommodate the evolving aviation system environment and higher levels of automation (AERA-2 in Figure 1-1). This may include additions to the new software and augmentation or replacement of the host computer. However, that decision can be deferred to the late 1980's and the need reaffirmed at that time.

The approach selected will satisfy all performance objectives. It will, with the sustaining engineering initiatives, provide sufficient computer capacity to meet current traffic demand (1981-1985), to provide available functional improvements and meet traffic demand in the near term (1985-1990), and to accommodate traffic demand, aviation system changes, and higher levels of ATC automation in the far term (1990-2000).

The study showed what steps would be required to meet the near term capacity requirements. Of the possible ways of providing this capacity, the host approach is the only one that provides significant improvements in hardware maintainability and reliability. Furthermore, it represents a first step toward the ulimate advanced automation system.

The plan has been strongly influenced by the desire for a more productive ATC system, one that makes more effective use of agency resources. Early development and implementation of a new sector suite will help to limit growth of the controller work force. A sector suite and system design to meet both en route and terminal requirements will, through hardware and software commonality, provide training and maintenance benefits. A common design is an important element of the facility consolidation that has been proposed as part of the National Airspace System Plan. Facility consolidation will be a major step towards more effective use of FAA resources.

Finally, emphasis on a new design (step 3) will give FAA an effective system for the future that can grow and adapt to the changing environment of the 1990's and beyond.

Recommendation 2. "FAA comprehensively evaluate and determine as a near term alternative to en masse replacement of the current system, the feasibility, cost/benefits and funding requirements of buying or leasing computers for centers determined to exceed capacity in the 1980's and of functionally splitting and upgrading the software."

FAA Action. The analysis conducted in response to Recommendation 1 indicated that increasing the capacity of the current computer hardware in the near term was necessary to provide for anticipated traffic growth, improved system reliability and constrained maintenance cost growth. Two feasible types of implementation: hardware augmentation and hardware replacement, were evaluated. Of these, only the hardware replacement strategy addressed reliability, maintainability, and productivity objectives and provided a suitable hardware base to accommodate the full replacement solution. This alternative was, therefore, incorporated into the solution selected as described in the response to Recommendation 1. A summary of the evaluations of the hardware replacement options recommended by the committee is presented in Figure 2-1.

Recommendation 3. "FAA develop a comprehensive, formal, far term plan to reflect agency strategies, goals, and objectives and be reviewed and approved by top management. The plan should set forth milestones for measuring and controlling activities, funding requirements, achieving efficient and effective use of resources and committing top management to action."

FAA Action. An approach to meeting near and far term en route computer requirements has been selected as a result of the analysis conducted in response to Recommendation 1. This approach has been formalized in conjunction with all other major capitalization programs and is described in the National Airspace System Plan. This plan shows the evolution of all FAA systems through the year 2000. It contains objectives, strategies, subsystem descriptions, and estimated schedules. A copy of the plan is enclosed with this submittal.

Recommendation 4. "The FAA develop a statement of goals for measuring overall efficiency of the current computer system, including processing requirements for general overhead and recording functions with accompanying plan and implementation schedule."

FAA Action. In late December 1980, the FAA convened a meeting of all regional directors and the Air Traffic and Airway Facilities Services division chiefs to develop an efficiency goal for the current computer system. The attendees established the computer operating system in use in the field at that time (NAS Software Release No. A3d2.10) as an operationally acceptable base for measuring the overall efficiency of the system. The base is given in terms of computer power utilization (CPU), which has been shown to exhibit a direct relationship to system capacity.

It is the goal of the FAA to ensure that this level of efficiency and processing workload is not adversely impacted in any way. As

HARDWARE REPLACEMENT OPTION EVALUATION

Figure 2-1

OPTION EVALUATION CRITERIA	MAINFRAME COMPUTER UPGRADE		OFFLOADING/SOFTWARE FUNCTIONAL SPLITTING	
	9020A to 9020 D Conversion	9020 Replacement (Instruction Compatible Hardware)	IOCE Replacement	Prime Channel DARC
PERFORMANCE/ CAPABILITY PROVIDED	• 9020D System provides 2.5 times the computational power of the 9020A	• 4 times the capacity of the 9020D system	• Offload a subset of 9020 CE functions into more powerful IOCE	• Increases 9020 capacity by offloading RDP functions
	• Current NAS software configuration could be augmented with some additional interfaces and near term functional improvements for metering and separation assurance			
RELIABILITY	• No improvement in system reliability	• Improvement in hardware reliability	• Improvement in IOCE reliability, though not significantly beyond that of current system	• Some improvement in primary channel RDP reliability, but redundant backup channel is lost
	• Future software enhancements will result in reliability problems due to structural complexity of software			
GROWTH/ CAPACITY	• Delays onset of operational delay days to 1996 or beyond for all centers	• Relieve all computational problems until well after year 2000	• Postpones delay day onset to 1991. Potential exists for additional capacity buyback thru further offloading of functions into IOCE	• Postpones delay day onset to 1990
MAINTAINABILITY	• New 9020D equipment not available from IBM • Existing software to be used without modification • Maintenance/Logistics impact low • Long-term provisioning of spare parts is limited to current stockpile	• 9020 software instructions can be supported on current generation machines • Long-term vendor commitment to operating system software and computer equipment expansion and maintenance • Requires real-time diagnosis/error analysis, automatic failure detection and recovery software to replicate 9020 system in new system architecture • Significant improvement in hardware maintainability	• Modules of system are strongly interconnected in terms of control flow and data usage. Therefore, splitting or offloading of software involves considerable redesign and some risk	
			• RDP offloading requires significant changes to existing NAS software with possible negative effect on software maintainability • Hardware maintainability improves slightly	• New RDP software in DARC is not in a higher level language • 9020 hardware maintainability unchanged, but addition of new hardware to DARC increases maintenance requirements
	Future software enhancements limited due to structural complexity of existing software			
ACQUISITION COSTS	• $64M for 10 centers • Memory increase from 3½ to 5 megabytes at all centers for additional $32M • Conversion of all 9020D memories from core to solid state reduces cost from $96M to $40M	• $226M = $117M (hardware acquisition) + $109M (development, site prep. and FAA costs) • 23 systems are procured	• $124M to convert an IBM 4341 to an IOCE "look-alike" including software costs	• $45M for prime channel DARC + software costs for the 9020 software modification
DEVELOPMENT/ IMPLEMENTATION SCHEDULE	• First operational system -- 1985	• First operational system -- 1986	• First operational system -- 1986	• First operational system -- 1986

NOTE: These options reflect the concerns identified in the Congressional Recommendations. As such, no single option includes the selected approach which is a composite of options and variations of options.

such, FAA will not implement any system update whose requirements would exceed the capacity savings associated with modifications underway as part of the current CPU buyback program. In addition, any functional additions to the system must be demonstrated to be totally offset by other system offloading initiatives.

In order to ensure compliance, the following actions are being taken:

1. Each new system, prior to its release to the field facilities, will be measured against the established base. This ensures a common reference for system sizing and performance.

2. An FAA order issued on May 21, 1981, requires each en route facility to report, on a monthly basis, the highest CPU utilization recorded (for a 5-minute average) for each calendar week. This provides a timely tracking tool for early identification of increased activity at individual sites.

3. The FAA has completed two management reports: (1) Computer Utilization at En Route Traffic Control Centers and (2) Traffic Loads and Computer Utilization Patterns at Twenty En Route Air Traffic Control Centers. The FAA will update these reports every six months. These reports will help identify effects of the projected increase in air traffic activity on CPU utilization at individual facilities.

All automation directives have been or are being revised to reflect the above actions.

Recommendation 5. "FAA establish a computer performance management function to systematically evaluate the capacity and performance of their computer systems. Staffing needs and costs for this function should be identified and reported to the committee for consideration."

FAA Action. Several activities are now underway that will enable FAA to follow computer performance more closely. Descriptions of each follow:

1. Configuration Management

2. System Evaluation: Two organizational changes, Configuration Management and System Evaluation Staffs, were originally scheduled to be completed by June 1981. The organizational changes were stopped until August 8 by a headquarters reduction-in-force. The PATCO strike on August 3 and the resulting emphasis on rebuilding the system has forced a further delay of implementation of these two organizational changes. It is not possible at this time to accurately forecast when these changes will take place.

3. Organization Review: The overall management of the automation system is being reviewed from three different perspectives. First, a group of automation experts from industry and government were assembled to evaluate software management approaches. This group reviewed how the FAA conducts its software development, implementation, modification, and maintenance, as compared with

other government and non-government organizations. A draft report has been prepared and is being reviewed. The report recommendations will be considered in the FAA's improvement strategy.

Secondly, a team is reviewing FAA's internal computer system management to identify any existing inefficiencies and to recommend their subsequent resolutions.

The third area being reviewed involves staffing and labor management considerations. When management reviews of the first two perspectives are completed, staffing/labor management will receive similar scrutiny.

4. Update Automation Directives: Existing directives that formulate the manner in which the FAA manages the automation system have been or are being revised. One such document, addressing the establishment of a joint Air Traffic and Airway Facilities Performance Improvement Program, was completed and approved on September 25, 1981. Another order, titled Management of NAS Automation Systems, is currently in the review cycle. Once adopted, the Performance Improvement Program will establish levels of facility-specific system performance review through the Associate Administrator level. This mechanism will draw increased attention to the system's operation.

Recommendation 6. "The reporting criteria of one minute or more for reporting an outage be dropped and all outages of any duration be recorded so as to determine their impact on safety and service to users."

FAA Action. The revised FAA facilities/services performance reporting system's known as the National Airspace Performance Reporting System (NAPRS), will provide for uniform reporting of all en route computer interruptions, regardless of length, by a single system. These interruptions will be reported in "seconds/minutes/hours."

It should be noted that FAA has always collected en route computer interruption data regardless of duration. Currently, interruptions of less than one minute are reported through a system separate from the system that collects interruptions of one minute or more. This data, regardless of duration, is used to improve en route computer performance.

By consolidating these systems in an automated environment, NAPRS will provide for more timely, accurate analysis of facility/service performance. NAPRS was scheduled for implementation in October 1981. Due to the PATCO strike and our subsequent desire to minimize disruptions in the National Airspace System, we have delayed implementation until January 24, 1982.

Recommendation 7. "FAA revise its reporting system to eliminate the practice of reporting unscheduled maintenance outages as scheduled outages. Scheduled maintenance should cover only regular periodic,routine preventive maintenance tasks. Reporting unscheduled outages as scheduled distorts performance reporting and recording of corrective maintenance actions."

FAA Action. Scheduled facility/service maintenance interruptions are redefined in the revised FAA facility/service performance reporting system. The intent of this revised reporting system, known as the National Airspace Performance Reporting System (NAPRS), is to consolidate various reporting functions into one comprehensive method for tracking system performance.

Scheduled maintenance interruptions have been redefined to provide separate categories for periodic preventive maintenance and planned corrective maintenance. Unplanned corrective maintenance will continue to be reported as unscheduled.

The FAA assures that facility/service performance evaluation will include both scheduled and unscheduled corrective maintenance interruptions.

Recommendation 8. "The FAA should give top priority to developing an adequate backup capability for the current en route computer system. This should include determining effective and economical alternatives to sole source spending of an additional $38 million to upgrade the direct access radar channel. Consideration of alternatives should include offloading the radar processing from the current system to peripheral computers which would serve as primary and backup thereby extending the life of the current system or an interim replacement system."

FAA Action. The FAA has given top priority to developing and implementing a sophisticated and reliable backup capability.

The DARC system is the product of several years of specification, design, solicitation, test, production and evaluation. This effort provided a formal review of alternatives presented by four competing companies. The Raytheon Company's alternative was selected, and a negotiated firm fixed-price contract was awarded on September 30, 1976. The FAA has now invested a total of $19.6M of the originally authorized $22M in program funding. This includes $14.7M for system production, test and installation; $1.7M for training and contract maintenance; and $3.2M for regional and other support services.

Delivery of all 22 systems to the FAA Technical Center, the FAA Academy, and 20 contiguous ARTCC's was completed on schedule in October 1980.

The DARC system was evaluated at the Salt Lake City ARTCC throughout 1980 and at the busy Washington and Chicago ARTCC's from October through December of 1980. These field evaluations demonstrated that the DARC system is operationally adequate. As a result, all systems were commissioned as of June 29, 1981. The original schedule called for complete commissioning by April 1981.

The evaluations conducted at the three ARTCC's during 1980 identified additional requirements necessary to ease the transition between the prime and backup systems. These requirements have been specified as enhancements to DARC. They would minimize the differences between the prime and backup systems by providing individual radar console switching or "punch in/punch out" capability, full flight identification data blocks, multiple radar coverage on each display, and an improved interface to assure that the DARC and prime systems display the same data. These enhancements will allow displays to remain in the vertical position and will make DARC a very effective backup with many of the functional capabilities of the prime Radar Data Processing (RDP) system.

It has been determined that alternative system designs necessary to meet the backup system requirements would not be economical. In addition to the loss of $19.6M already invested in DARC, cost of development and implementation of a new system design is estimated at four to five times the current backup system investment. A new system would also require reestablishment of logistic support and retraining of controllers and technicians.

Implementation of a new system would be expected to take five years, one year of effort prior to contract award and four years for development and implementation. A new system would involve significant technical, cost, and schedule risk because of the requirement to begin work with a new contractor on a new design. The DARC system has been proven, and the required enhancements appear to present a low technical risk.

Given the above and the present status of the DARC system, the FAA has budgeted $42M for DARC enhancements.

The FAA agrees that it should develop a backup capability that can perform the necessary radar data processing functions. The agency is examining such a capability in its program to enhance the DARC system. Offloading RDP into other peripheral computers would present technical and schedule risks similar to those addressed for providing a new backup system. In addition, costs for other computers would be considerably higher than the costs involved in using the existing DARC computers as a base.

A study of alternatives for offloading RDP into DARC is complete. Results of this study show the enhanced DARC RDP system could be upgraded to allow removal of the current primary system RDP functions (Prime Channel DARC).

The feasibility of these alternatives was considered along with other alternatives in reaching the final FAA decision on the approach for replacement of the IBM 9020 en route computers.

Ref. 0015C (0342C)

Appendices

1. Meeting En Route Air Traffic Control Requirements in the 1980's and 1990's - An Option Analysis

2. Operational Delay Day Forecasts for the Twenty Air Route Traffic Control Centers for the Years 1982 through 2011.

3. Economic Analysis of Investment Options to Replace the En Route Center Computer System - A Quantative Assessment of Benefits and Costs

APPEDDIX — 1

Meeting En Route Air Traffic Control Requirements

In the 1980's and 1990's

An Option Analysis

FOREWORD

This document presents the background rationale and requirements that constituted the basis for the examination of the various alternative solutions for the future Advanced Automation System. Candidate options were analyzed for application in both the near and far term. The analysis, screening and evaluation of the options/suboptions and various combinations provided the information data base used in the numerous scenarios considered in the Administrator's review and evaluation of the Advanced Automation Program. Using the information developed in the various evaluations of the specific options, it was possible to compare options, combinations of options and variations of options in assessing the combinations of options and variations of options in assessing the more viable choices. Consequently, as each of the scenarios was scrutinized, it was possible for the Administrator to evaluate and choose the more desirable characteristics of the various options to formulate a specific course of action for the Advanced Automation Program. It should be noted that the selected approach does not represent any of the specific options evaluated and may be higher cost since two separate sets of parallel contracts will be used with a longer competitive phase for the System contractors. One set of contracts will be for the Host hardware that will provide earlier increases in computer capacity while the second set of contracts for the system will provide for early sector suite implementation to obtain productivity gains as the forerunner to the total system replacement.

Meeting En Route Air Traffic Control Requirements

in the 1980's and 1990's - An Option Analysis

Executive Summary

EXECUTIVE SUMMARY

1.0 Introduction

As part of the Advanced Computer Program, FAA has been evaluating a series of options for meeting the growing requirements being placed on the en route computer system by increases in traffic and by the need for increased safety, productivity, and fuel efficiency. The option evaluation was done against a background of evolving requirements and an assessment of the capability of the present en route ATC computing complex to meet these needs. The particular options analyzed were selected to cover a spectrum of alternatives for meeting FAA's mission and to provide a full response to the October 1980 Recommendations of the Senate Appropriations Committee regarding FAA's en route ATC system.

The options were defined and a major portion of the analysis performed prior to the August 3, 1981, PATCO strike. As a result current priorities may be somewhat different from those assumed for this study. For example, the initial analysis gave the replacement of computer hardware and software precedence over the implementation of a new sector suite. The present situation suggests that the sector suite should now be an early deliverable of the replacement system. None of this, however, affects the validity of the options analysis. The cost, technical transition, and schedule results remain valid.

The options evaluated address the following issues:

(a) the need to install a replacement system that will correct the limitations of the existing system and provide the capabilities needed to meet future needs;

(b) the alternatives for enhancing the current system to extend its operational life during the replacement system acquisition cycle;

(c) the relative merits of buying or leasing computers for those centers likely to exceed capacity in the 1980's as a short range alternative to complete replacement of the current system; and

(d) the merits of functionally splitting and upgrading the software as a short-range alternative to complete replacement of the current system.

The options that were evaluated fall into two broad groups:

(a) Options 1-4, which were aimed at solving the near term capacity and reliability issues without regard to the desire for increased levels of automation, and

(b) Options 5-8, which were aimed at providing in the far term a system capable of satisfying FAA requirements for improved performance, greater levels of automation to increase controller productivity, and increased system capacity.

This Executive Summary presents an overview of these options. The complete option analysis report that follows provides a detailed statement of the pros and cons of each option.

2.0 NEAR TERM OPTIONS

FAA analyzed four options to determine their suitability to satisfy the near term computer capacity needs of the ATC system. These are interim approaches designed to fill the void until a full replacement system can be made available. Thus, the major goal is to provide needed capacity quickly and at reasonable costs. These options also focused on the suggestions made by the Senate Appropriations Committee. Ability to support evolution to the advanced ATC automation functions was not a factor in defining these options. The objective was simply to identify a range of potential approaches to the capacity enhancement issue. These ranged from making no changes at all to complete replacement of the 9020 computers with new equipment. The options placed more emphasis on the 9020A systems than on the 9020D, reflecting the near term processing capacity shortfall forecast for a number of the 9020A centers. These forecasts were made before the air traffic controllers' PATCO strike on August 3, 1981. No attempt has been made to adjust the forecasts to reflect this event, because it is believed that it will not have any long term impact on demand for ATC services.

Option 1, Base Option; Continue with Present System ("Do Nothing").

Under this option, FAA would undertake no activities beyond projects already in progress. Upon analysis, this approach proved insufficient to meet expected demands beyond the mid 1980's.

Option 2, Increase 9020 Capacity. This option considers several means of enhancing the capacity of the 9020. Both hardware enhancements and operational changes are included, but all would retain the existing hardware architecture and application software. Two approaches (upgrading 9020A's to 9020D's and increasing the power of the 9020A's by increasing the processor speed and adding more and faster memory) had some potential value.

The others proved, for various reasons, to be inadequate capacity buyback solutions.

Option 3, Offload Functions from the 9020. This option examines two alternatives for functionally splitting the 9020 ATC applications software to allow significant pieces to be off-loaded from the 9020 compute elements to other processors. This would relieve the 9020 Compute Elements (CEs) of part of their processing load. This approach represents a more extensive change than option 2 since both hardware and software must be modified or replaced. The alternatives considered were:

(1) replacement of elements of the 9020 with more powerful processors to permit reallocation of functions within the 9020 and

(2) off-loading of some functions from the 9020 to an external system.

FAA analyzed one approach in each of these categories.

Option 3a, Input/Output Control Element (IOCE) Replacement. Under this approach, the input/output control elements of the 9020 would be replaced with machines that reflect current technology and that have more processing power and larger memory. Some of the programs that are now executed in the 9020 compute elements could then be off-loaded to be executed in the new IOCEs. Significant software changes would be needed to achieve any appreciable capacity recovery under this option. This approach appears feasible but involves certain technical and schedule risks.

Option 3b, Prime Channel DARC. The Direct Access Radar Channel, a back-up system, would be expanded to take over the radar data processing functions during normal operation, thus off-loading the 9020. This approach reflects the suggestion in the Senate Investigations Staff Report to explore off-loading radar data processing to peripheral computers. The approach appears feasible, but software splitting involves major effort with some technical and schedule risks.

Option 4, Replace 9020 Hardware, Keep Software. Under this option, the 9020 computers would be completely replaced by new computers that can accommodate the 9020 software. This would permit replacement of the 9020 computer and, if deemed necessary, the display channel hardware while retaining the existing 9020 software. This option is responsive to the Senate report, which says, on page 87, "FAA should consider procuring an interim system replacement..." The high cost of such a computer hardware replacement does not warrant its consideration as a near term capacity solution unless it also forms a part of the replacement ATC computer system. Two variations of this type of computer replacement were analyzed.

Option 4a, Full Rehosting Activity. The interim computer system would include new peripheral equipment, to take full advantage of the latest hardware technology. The software would be upgraded to operate the new peripherals and to take advantage of other features of the new hardware. This approach is feasible. It would require almost six years, from issuance of an RFP to full operation at all sites, to implement.*

Option 4b, Accelerated Rehosting Activity. This sub-option would minimize the cost of the interim system by keeping the old peripherals and by limiting the software changes. Cost and schedule would be less than for option 4a, but reliability would also be less and schedule risk greater.

3.0 FAR TERM OPTIONS

FAA examined several far term approaches to full replacement of the existing en route ATC computers and to the introduction of advanced automation functions into the ATC system. For all far term options considered in this analysis, it has been assumed that the computers would be replaced before the sector suites. All far term options include an initial competitive phase that produces a concept/design for a total system (hardware, software, and controller stations) through the evolution to advanced automation.

*The option selected is a variation of the Option 4a and 4b and reflects a resultant accelerated schedule.

These far term options fall into two major categories, depending on the approach taken to the near term problem. Options 5 and 8 apply if an interim computer system executing the existing software (Option 4) is used to solve the near term problem. Options 6 and 7 apply if one of the other near term options is chosen. For clarity of presentation, the options are discussed by category and are thus out of numerical order. (to retain continuity with earlier documents and presentations, the options have not been renumbered).

In the first category, the near term system has a significant impact on the replacement approach, either by deferring a full replacement or by becoming an integral part of the replacement system. In the former category, the near term capacity solution is considered a "throw-away" and therefore places no constraint on the full replacement option. The analyses of options 6 and 7 do not include cost or impact of the particular near term system chosen to provide additional capacity.

In all the discussions that follow, "Interim System" refers to new computer hardware executing the existing software, as per options 4a and 4b. "Replacement System" means both new hardware and software, but without the advanced automation functions that represent the evolution to the AERA system. These advanced functions include direct route processing, fuel-efficient flow planning, conflict prediction, and conflict-free clearance generation. "Advanced Computer System" refers to an ultimate configuration of new hardware and software that provides all the advanced automation functions.

If an interim computer is chosen as the solution to the near term problem, then a fundamental next question is: should the interim computer be kept as part of the far-term system, or should it be replaced? Option 5 and 8 examine these alternatives.

<u>Option 5, Interim Followed by Full Replacement System.</u> This option responds to the suggestion of the Senate Investigations Staff Report that the FAA consider an interim system to solve near term capacity problems and that it defer a full replacement until a better definition of long term requirements is in hand. It is assumed for this option that the interim system not be retained in the advanced system. Therefore, Option 4b is chosen as the near term solution, in order to minimize the cost of the interim system. Availability of full requirements for advanced automation makes it possible for the advanced computer system to be developed in a single step. This in effect by-passes the replacement system step.

<u>Option 8, Replacement System Built Around Interim Host.</u> Under this option, the interim computer system becomes the first building block for the replacement system and eventually for the advanced computer system. Depending on the urgency of the near term capacity enhancement requirement, either option 4a or option 4b could be selected as the interim for this option. Because the interim system in this option will also be kept for the far term, it is appropriate to buy all new peripherals with the interim. Thus, for analysis purposes option 4a is chosen as the near term approach for this option. A replacement system development effort is started concurrent with the interim rehosting effort. Following a full concept/design phase, the replacement software is designed and written to provide a suitable far term base. Both the hardware and

software will then be enhanced to create the advanced computer system. Two sub-options explore alternate means of moving from a replacement system to an advanced computer system.

Option 8a, Distributed Approach. This option keeps the replacement system hardware. Additional processors external to the mainframe computer will provide the hardware enhancements needed for the advanced computer system.

Option 8b, Mainframe Approach. This sub-option will provide hardware enhancement for the advanced computer system by substituting a large mainframe of the same family (presumably incorporating the latest technology) for the replacement system hardware.

Options 6 and 7 explore alternatives in which the computer replacement program is not affected by the approach selected for increasing near term capacity. Because the near term approach is not a factor in the analyses of these two options, the cost comparisons between the long term options must take into account the fact that only 5 and 8 include the cost of a near term solution.

Option 6, Multi-Step Transition to Replacement. This option would replace the 9020s in two steps. The first step would replace the radar data processing and display portions of the existing hardware and software; the second step would replace the remainder of the system. The aim of a multi-step approach is to replace the 9020 in smaller, more manageable steps. Deferring acquisitions as long as possible permits the buyer to take best advantage of rapidly-moving technology. After the two-step replacement, a third step would upgrade to the advanced computer system.

Option 7, Single-Step Transition to Replacement System. In this option, the 9020s would be replaced in only one step. The replacement system would subsequently be upgraded to the advanced computer system.

Option 7 formed the basis of FAA's early replacement program planning. It has been presented to Congress and, at a special meeting on December 2, 1980 to the industry at large. Based on numerous discussions regarding OMB Circular A 109 with the Office of Federal Procurement Policy, three alternative acquisition strategies were analyzed in detail for option 7. The conclusions drawn from this acquisition strategy analysis apply to all far term options. However, in cases where hardware is procured early, the duration of competition needs to be limited since hardware cannot be ordered until all but one contractor have been eliminated.

The following figure illustrates FAA's comparison of the far term options analyzed.

TABLE V-1

EVALUATION OF FAR TERM OPTIONS

	INTERIM			NO INTERIM	
	5	8A	8B	6	7
SCHEDULE	A93*	R90 A92	R90 A92	R89-91** A93	R89** A92
COST	1.50B	1.39B	1.45B	1.38B	1.39B
RISK	LOW	ARCHITECTURE MAY CONSTRAIN DESIGNS FOR HIGHER LEVELS OF AUTOMATION		SOFTWARE SPLIT	LOW
IMPACT ON FAA RESOURCES	MED-HIGH	HIGH	HIGH	HIGH	MED
ABILITY TO EVOLVE	***	MED	MED	MED	***
TRANSITION IMPACT	MED-HIGH	HIGH	HIGH	HIGH	MED

*ACS SYSTEM IS AVAILABLE, BUT ADVANCED AUTOMATION WILL NOT BECOME AVAILABLE UNTIL 94 or 95
**ASSUMES OPTION 2 OR OPTION 3 IF NEEDED (COST NOT INCLUDED)
***UNCONSTRAINED. WILL RESULT FROM DESIGN PHASE

Note: The specific options that were evaluated and indicated herein, reflect the concerns identified in the Congressional Recommendations. As such, the selected approach does not appear explicitly in this table.

R-year of replacement system
A-year of ACS

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FIGURES

Figures (cont'd)

Chapter I Introduction

This report summarizes the results of a detailed analysis of alternatives or options for meeting the ATC en route automation system requirements to the year 2000 and beyond. To fulfill the FAA's mission, the automation system must provide adequate capacity to accommodate growing demand and have the ability to support ATC evolution.

The option evaluation is done against a background of evolving requirements (Chapter II) and an assessment of the suitability of the present ATC computing complex to meet these needs. The options for meeting both near term capacity needs and far term automation requirements are evaluated in terms of specific transition impact, criteria of cost, schedule, benefits, feasibility, transition impact, and risk. No recommendation is made, but all information required by FAA decision makers to tailor an ATC automation program to meet their near and far term objectives is provided. While this report was written prior to a decision on an ATC automation program, a decision is inherent in the FAA "National Airspace System Plan" that was submitted to Congress in December 1981.

The particular options analyzed were selected to cover a spectrum of alternatives for meeting FAA's mission and to provide a full response to the October 1980 Recommendations of the Senate Appropriation Committee's recommendation regarding FAA's en route air traffic control computer system. 1

I.1 Background

A major element of the Federal Aviation Administration's (FAA) mission is to provide safe and efficient air traffic control (ATC) services. To support this mission in the en route environment, FAA maintains and operates, at each 20 Air Route Traffic Control Centers (ARTCCs), an ATC automation system consisting of high availability computers and 30-60 controller display suites.

Although originally acquired during the 1960's, the existing IBM 9020 en route computer systems have been substantially improved to provide current high levels of productivity and efficiency. On-going efforts to improve the existing system by providing full expansion of the computer configuration, software changes to improve efficiency, and off-loading of some non-control functions will ensure that the future demands on the system can be met well into the 1980's.

The existing en route computer system is based on 1960's technology. By the late 1980's, the FAA's ability to accommodate aviation growth and introduce system improvements will be limited by existing capabilities. Some new automation functions may be added to the existing operational system if unused capacity is available when they flow from the developmental pipeline, but implementation of major new automation functions will not be possible with the existing en route computer system. Because of the 1960's hardware

and software technology embodied in the 9020's, maintenance costs are significantly higher than they would be for a comparable system based on technology of the 1980's.

For the above reasons, the FAA designated, in November 1978, the ATC computer replacement program as a major system acquisition.[2] The scope of the program includes replacement of the ATC computer and display systems at the 20 ARTCC's, at the three off shore centers (San Juan, Puerto Rico; Anchorage, Alaska; and Honolulu, Hawaii) and at FAA's en route ATC development support and training facilities.

The need for replacement of the en route automation systems has been recognized by Congress, most notably in the Senate Appropriation Committee Investigation's Staff Report on FAA's En Route Air Traffic Control Computer System (Report No. 80-5, October 1980)[3] and in the August 1981 report <u>Air Traffic Control En Route Computer Modernization</u> prepared by the Subcommittee on Transportation, Aviation, and Materials of the Committee on Science and Technology, U.S. House of Representatives.[4] The ATC user community and aviation industry representatives emphatically endorsed the computer replacement in their 1979 consensus views on New Engineering and Development Initiatives -- Policy and Technology Choices[5]. On a more general note, a recent GAO report stated that the "continued use of costly, out-moded computers in Federal Agencies can be avoided" (GAO Report AFM-81-9, Dec. 1980.)[6]

The initial activities of the FAA's Computer Replacement Program centered around an identification and analysis of ATC requirements and an investigation of applicable hardware and software technology. In parallel with these activities, FAA prepared a preliminary replacement plan consistent with OMB Circular A-109. This plan was presented at the Air Traffic Control Computer Replacement Industry Briefing on December 2, 1980.[7] Implementation of a replacement system was estimated to take place from late 1988 to 1991.

At the industry briefing, FAA indicated that a 9020 life expectancy analysis was underway to select a well founded computer transition strategy for the 1980's. The results of that analysis[8] (also included as Appendix 3) confirmed the Senate Appropriation Committee's concern that the 9020 systems would not be able to handle the projected traffic growth until a replacement system is in place.

I.2 Purpose of this Report

In the normal course of initiating a major systems acquisition, analysis and studies are conducted to develop the documentation and supporting material necessary in establishing the mission need, establishing and validating program requirements, costs and benefits, alternative courses of action, acquisition strategies, implementation plans and transition plans.

The purpose of this report is to bring together, summarize and document the results of a number of supporting studies and activities (system requirements analysis, 9020 life expectency, cost benefit analysis). Specifically, the report provides a comprehensive analysis and evaluation of alternative technical approaches for evolving to the advanced ATC automation system. Near-term technical approaches for enhancing the current system to provide adequate computer capacity until the system is replaced are included in this analysis and evaluation. Program costs, schedules and acquisition strategies for the near-term and advanced automation system alternative approaches are established. This report provides the alternatives analysis to support the Acquisition Paper to be submitted to the Department of Transportation for program review and acquisition approach review and approval.

The options selected for analysis cover a broad range of approaches to meeting the FAA needs. Each option is a representative example of a broader category of solutions. Option 6, for example, considers replacing first the radar data processing functions of the 9020 and later the flight data processing functions. As such, it is representative of the general strategy of phasing out the 9020 system in several steps. The option analysis was performed with the full expectation that the approach ultimately selected for meeting FAA's automation requirements, would very likely be a variation of one of the options or a combination of the desirable features of several options.

The options were selected and most of the analysis done prior to the August, 1981 PATCO strike. Since that event, FAA has placed considerably more emphasis on productivity in both the ATC and maintenance areas. For that reason, early implementation of a sector suite, facility consolidation, and commonality of en route and terminal automation equipment are being considered in FAA's automation planning effort. This option analysis did not specifically consider early sector suite implementation and limited the evaluation of options to today's en route center configuration. Nevertheless, the cost, technical, transition, and most schedule results remain valid and can be used in an evaluation of the en route portion of the automation program.

This report is summary in scope and only includes sufficient detail to provide the reader with an understanding of the significant issues and considerations which would influence the selection and evaluation of alternative approaches for meeting near and far term ATC automation requirements. The detai' ' requirements studies and analysis supporting this report are referenced above and have been published separately. Additional significant contributiuons were made by the references listed below:

- Cost Feasibility Study of ATC Computer System Options, The Analytic Sciences Corporation, October 1981.9

- Feasibility of Dual DARC (Prime Channel DARC), The MITRE Corporation, September 1981.10

- A Technical Analysis of Rehosting the National Airspace System Software, Federal Aviation Administration, October 1981.11
- An Analysis of Selected Enhancements to the En Route Central Computing Complex, The Federal Aviation Administration, September 1981.12
- Economic Analysis of Investment Options to Replace the En Route Center Computer System, The Federal Aviation Administration, November 1981.13
- Technical Analysis of IOCE Replacement, The Federal Aviation Administration, June 1981.14

I.3 Outline of Report

Chapter II: Requirements

This chapter identifies the mission need and goals for the en route ATC system; the demand for ATC services is projected; current and future functions required to satisfy the mission over the next twenty years and the benefits of these functions are presented; finally the specific requirements that the computer system must satisfy to meet the mission need are derived.

Chapter III: Assessment of the Current System

In this chapter the technology and capabilities of the current system are identified; the potential for enhancing the current system is examined; and constraints of the system (hardware and software) to meet the evolving capacity and functional requirements presented in Chapter 2 are discussed.

Chapter IV: Near Term Options

This chapter defines four alternative approaches, referred hereinafter as options, for satisfying near term system capacity requirements; identifies the critical evaluation criteria; provides the detailed analysis results and comparative evaluation of the options; and identifies the most promising options.

Chapter V: Far Term Options

This chapter defines four options for evolving to the advanced ATC automation system which satisfy the far term mission need; identifies the critical evaluation criteria; and provides the detailed analysis results and comparative evaluation of the options. Several alternative acquisition strategies are evaluated.

II. Requirements

II.1 Purpose and Organization of this Chapter

A major part of the FAA's mission is to provide safe and efficient air traffic control services. To successfully carry out this mission, the FAA must pursue the goals of high safety, fuel efficiency, high controller productivity, delay elimination and low maintenance cost. The computer system is adequate to meet the FAA's mission today (Sec. II.2), but as the demand increases and ATC evolves, the requirements on the computer will change. The ATC system must handle increasing demand without deterioration in the quality of ATC Service (Sec. II.3). As time passes and the environment in which ATC is carried out changes, new functional capabilities will have to be added to the system to allow the FAA to carry out its mission (Sec. II.4).

The purpose of this chapter is to develop the requirements that the ATC computer system must satisfy (Sec. II.5), to show how these requirements change over time as the environment changes, and to indicate how having a computer system that satisfies these requirements will put the FAA into a position from which it can fulfill this part of its mission.

II.2 The FAA's ATC Mission

The FAA is officially charged with the responsibility of promoting the safe and efficient use of the national airspace. This responsibility has been stated in terms of a number of missions and has provided the basis for developing the overall ATC system. This system includes surveillance systems, communications, avionics, weather information services, and navigation aids as well as a computer system that assists controllers in coordinating air traffic. Two of the FAA mission elements deal directly with traffic control. These are:

- The control of the use of navigable airspace of the United States and the regulation of both civil and military operations in such airspace in the interest of safety and efficiency of both.

- The development and operation of a common system of air traffic control and navigation for both civil and military aircraft.

The portion of the FAA's mission that is relevant to en route automation and therefore to this report is to provide the ATC services that lead to safe and efficient use of the nation's airspace. The specific goals that relate to the effective accomplishment of this mission are:

- ensuring safety,
- promoting fuel efficiency,
- increasing controller productivity,
- eliminating delay, and
- holding down maintenance cost.

The first of these five goals deals with safety and the last four deal with various aspects of efficiency. Each of these five goals will now be discussed.

Safety. In the context of the ATC system, safety is simply the absence of collisions and near misses. To achieve this goal, the FAA specifies separation standards between aircraft and between aircraft and the ground. Once these separation standards are set, it is the job of ATC to see that they are achieved. The present system has an outstanding safety record; the task for the future is to maintain or improve that record in the face of steadily increasing traffic and ATC evolution to accommodate the other four, efficiency-oriented goals.

Fuel Efficiency. This goal can be approached in three complementary ways. First, ATC can be flexible and provide routes that use less fuel because they are more direct or take better advantage of prevailing winds. Second, ATC can accommodate more efficient profiles, i.e., ascent and descent are accomplished in a fuel efficient manner. Third, the interactions among aircraft can be planned so that deviations from fuel efficient flight for safety reasons becomes unnecessary.

Controller Productivity. Any government program has as a goal the high productivity of its workforce. The FAA has a specific need to increase the productivity of the ATC system, both in terms of the maintenance and air traffic controller workforces. This need stems in part from the expectation that air traffic will increase significantly over the next two decades. The FAA will depend on increased ATC automation to service this increased demand without excessive growth in controller staffing. Repetitive, routine tasks will be shifted from the controller to the computer system, thus changing the controller's role from that of second by second planner and clearance generator to one of a manager who handles exceptions and supervises the operation of the automation system. In this way, the number of aircraft supervised by each controller can be increased significantly.

While automation is needed for greater productivity, automation may also be required to handle the projected growth in traffic because there are indications that the way that the ATC system has handled increases in traffic in the past can no longer be used. As air traffic increases, the number of aircraft in some sector, (the space under the supervision of a single controller or single team of controllers) increases until eventually, the number of aircraft in these sector becomes so large that they cannot be effectively controlled by a single control team. In the past, the

response to this increase in traffic has been to resectorize, i.e., to redivide the area into a larger number of smaller sectors; this would reduce to a manageable level the number of aircraft controlled by a single control team.

The problem with increasing the capacity of the system by increasing the number of sectors is that this approach reaches a point of diminishing returns. As sectors grow smaller, more handoffs and other coordination are needed. Eventually sectors get so small that a further decrease in sector size leads to more work for the controller rather than less. An analysis of the New York and Cleveland centers shows that for some sectors this point of diminishing returns has been reached, and further sectorization provides no increase in capacity. Reference Mitre Corportation Trip Reports, W40-2209, 2210, 2211, by R. Rucker, August 6, 7, 20, 1981.

In short, the expected increase in traffic means that there is a pressing need to increase the number of aircraft that a controller can supervise, and more automation of the control process appears to be an essential element in achieving this increase in productivity.

FAA is currently conducting two studies aimed at improving the efficiency of the existing and future ATC system. The results of these studies will complement increases in the level of automation in an overall effort to limit the growth of the controller workforce. The first of these studies is a National Airspace Review encompassing airspace and procedural aspects of the air traffic system. It is a joint FAA-aviation industry venture to improve the efficiency and effectiveness of the present ATC system incorporating existing technological improvements. This study will address a variety of possible improvement areas including a look at changes in en route sector and center boundaries, random routes, fixed route evaluation (RNAV), quota flow, changes in traffic patterns and altitudes, consolidation of U.S. oceanic ATC control centers, en route metering, etc. The second study developed the detailed National Airspace System Plan for the agency to the year 2000. This plan, copy attached, calls for facility consolidation to decrease the overall number of ATC facilities and thereby increase controller productivity and reduce costs.

Delay. Today, controller dependence on the ATC computer is such that if the computer cannot handle the demand placed on it or if it fails, then significant air traffic delays result as aircraft are delayed in the air or held on the ground. Sufficient machine capacity and availability are required so that the controller can get the automation system support needed in a timely enough manner to provide efficient ATC service. In addition to having a computer system with adequate response time available at all times, the controller must be provided with specific functions in the computer to provide assistance in planning traffic flow to minimize airborne delay.

Maintenance Cost. In a computer system like the one used for ATC, which has a long life, numerous expected modifications, and high availability requirements, maintenance cost comprises a

significant portion of the life-cycle cost. Hardware maintenance cost is incurred in replacing, repairing, and otherwise servicing the hardware. Software maintenance cost is incurred in detecting and correcting errors and in modifying the system to give it new capabilities. Efficient operation of the ATC system requires that the computer system be designed to hold maintenance cost down.

II.3 Demand

To properly plan the evolution of the ATC system to meet the goals just outlined, FAA prepares extensive traffic forecasts. In May of 1981 a special forecast was prepared to assist in the evaluation of ATC computer system load. Peak airborne counts were projected for each en route center for the years 1980 to 2011 (Table II-1). (The peak airborne count is the number of aircraft for which the computer system must provide tracking, flight plan processing, and other automation functions.) The peak count is the largest number of aircraft that is sustained over any seven minute interval during the year. The seven minute interval is derived from GENOT RWA 8-11 dated 1/20/78, which states that whenever the CPU utilization reaches 80% for a sustained interval of 5 minutes, then shedding procedures shall be instituted. (A GENOT is a general notice/command to FAA field operations.) The additional two minutes represent an attempt to smooth the data by providing an additional minute before and after the GENOT criterion. Thus, Table II-1 shows that for the Boston ARTCC in FY1985, the forecast is that there will be a seven minute period in which the peak airborne count is 191. If we take 1981 as the base year and let the traffic level be 100, then the aggregate traffic levels in 1985, 1990, 1995 and 2000 are 118, 144, 172, and 200, respectively. This gives an idea of the increase in activity that the ATC system will be called on to service.

These forecasts were made before the air traffic controllers' PATCO strike on August 3, 1981. No attempt has been made to adjust the forecasts to reflect this event because it is believed that it will not have any far term impact on demand for ATC services.

II.4 ATC Functional Improvements

II.4.1 Introduction

Today, the primary functions of the 9020 computer system are Radar Data Processing (RDP) and Flight Data Processing (FDP). RDP takes inputs from many surveillance sites, performs (automatically initiated) tracking on targets, associates the tracks with flight plans, and presents a composite, all digital display of aircraft track and aircraft information to the controller at a sector suite. Normally there is one display per sector.

FDP accepts flight plan information, and as the aircraft flies through a center's airspace, updates this information and prints flight progress strips at appropriate sector positions. There are

CENTER	ID	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96
BOSTON	ZBW	166	166	171	176	183	191	199	205	212	219	227	234	242	250	258	265	272
NEW_YORK	ZNY	224	221	225	231	238	248	258	266	273	280	290	296	305	314	322	330	337
WASHINGTON	ZDC	254	254	262	272	282	295	310	323	333	344	357	368	381	395	407	420	431
ATLANTA	ZTL	259	260	270	282	296	313	330	344	359	373	392	407	424	444	461	479	496
JACKSONVILLE	ZJX	202	203	209	216	224	235	244	253	263	272	283	292	303	314	325	335	345
MEMPHIS	ZME	268	268	276	287	298	314	327	342	356	371	387	400	416	434	451	467	483
MIAMI	ZMA	226	230	239	251	264	279	296	306	320	332	349	362	377	394	409	424	436
CHICAGO	ZAU	319	319	331	347	363	384	405	425	445	463	486	504	526	551	574	597	619
CLEVELAND	ZOB	303	297	304	315	326	340	356	369	351	394	408	419	434	449	463	477	489
INDIANAPOLIS	ZID	267	264	272	282	294	308	323	339	351	368	383	396	413	431	448	465	481
MINNEAPOLIS	ZMP	217	218	226	236	248	263	277	290	303	317	333	347	362	380	396	412	428
KANSAS_CITY	ZKC	288	290	300	314	329	346	364	378	392	406	422	433	449	466	481	496	510
ALBUQUERQUE	ZAB	261	264	272	279	288	298	309	316	325	334	346	354	363	374	383	392	400
FORT_WORTH	ZFW	304	306	315	329	343	359	377	391	406	421	437	450	467	485	501	517	532
HOUSTON	ZHU	221	228	238	249	262	277	295	308	324	338	355	368	385	404	421	438	455
DENVER	ZDV	305	309	324	340	359	330	403	420	437	455	476	495	516	539	559	581	601
SALT_LAKE_CITY	ZLC	231	233	239	248	256	266	278	287	295	304	315	323	333	344	354	363	372
LOS_ANGELES	ZLA	255	257	263	273	284	297	310	321	333	343	357	368	382	396	409	421	433
SEATTLE	ZSE	217	223	235	247	261	276	297	311	326	341	357	370	336	405	422	439	456
OAKLAND	ZOA	240	242	247	256	263	274	284	293	301	308	319	327	336	347	355	364	372
ALL CENTERS	TOT	5027	5052	5218	5430	5661	5944	6242	6486	6735	6963	7279	7513	7800	8116	8400	8632	8950

CENTER	ID	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11
BOSTON	ZBW	279	287	293	301	308	314	320	326	332	337	342	346	351	353	357
NEW_YORK	ZNY	343	351	358	365	372	378	384	389	394	398	402	404	408	410	412
WASHINGTON	ZDC	442	455	466	479	497	502	512	522	532	541	550	557	566	571	578
ATLANTA	ZTL	513	532	549	569	588	605	623	640	657	673	690	704	723	734	749
JACKSONVILLE	ZJX	354	365	375	386	396	405	415	423	432	440	448	454	462	467	474
MEMPHIS	ZME	499	516	532	550	568	583	599	614	629	644	658	671	685	696	709
MIAMI	ZMA	452	469	483	500	516	530	545	559	573	536	600	612	625	635	647
CHICAGO	ZAU	641	666	689	714	740	763	786	809	832	854	876	896	919	937	957
CLEVELAND	ZOB	502	516	528	541	555	566	578	588	599	608	617	625	634	640	647
INDIANAPOLIS	ZID	497	515	531	550	568	584	601	616	632	648	663	676	692	703	717
MINNEAPOLIS	ZMP	444	462	478	496	515	531	548	564	581	597	613	628	644	657	672
KANSAS_CITY	ZKC	523	539	553	568	583	596	609	621	633	644	655	664	675	682	691
ALBUQUERQUE	ZAB	408	417	424	432	441	446	453	458	463	468	472	475	479	480	483
FORT_WORTH	ZFW	547	564	578	595	612	625	640	653	666	678	691	701	713	721	731
HOUSTON	ZHU	472	490	508	527	546	563	582	599	617	633	651	666	683	697	713
DENVER	ZDV	621	644	664	687	710	730	751	771	791	810	829	846	865	879	897
SALT_LAKE_CITY	ZLC	380	390	398	407	416	423	431	437	444	450	455	459	465	468	471
LOS_ANGELES	ZLA	444	458	469	482	495	505	516	527	537	546	555	563	572	577	585
SEATTLE	ZSE	472	491	508	527	546	563	581	593	616	632	649	664	681	695	711
OAKLAND	ZOA	380	388	396	404	412	418	425	430	436	441	445	448	453	455	457
ALL CENTERS	TOT	9213	9515	9780	10080	10379	10630	10899	11144	11395	11628	11861	12059	12293	12457	12653

Table II-1. Peak Airborne Count Forecast for each ARTCC, 1980 - 2011

provisions for entering new and revised flight data at all operational positions. The 9020 computers provide the means for intersector coordination and interfacility coordination through use of computer-transmitted data. This allows aircraft to be "handed off" from one controller to another. Two other functions, conflict alert and minimum safe altitude warning, aid the controller in maintaining the safe and expeditious flow of air traffic. The conflict alert function warns the controller when two aircraft are predicted to have less than standard separation within the next two minutes. When a conflict is detected, the controller is warned by a computer-generated conflict message and by flashing of the data blocks for the affected aircraft. Minimum safe altitude warning requires the computer to determine whether an aircraft is predicted to be below a predetermined safe altitude in the next several minutes.

While these functions are currently sufficient to provide safe and efficient ATC, it is expected that additional functions will be necessary over the next two decades as air traffic increases and as changes occur in technology and in the ATC environment. For these reasons, the FAA has proposed eleven key functional improvements to be added to the system. Seven of these vital functions are nearing completion of their development cycle and will be ready for implementation in the 1980's:

1) Conflict Alert for VFR Intruders (CA/VFR),
2) Conflict Resolution Advisories (CRA),
3) En Route Metering (ERM),
4) Electronic Tabular Display Capability in Sector Suite,
5) Mode S Interface,
6) Central Weather Service Unit Interface (CWSU), and
7) Terminal Information Display System Interface (TIDS)

Four longer term functions, representing much higher levels of ATC automation, will be ready for implementation in the late 1980's and 1990's. These are:

8) Direct, fuel-efficient route planning,
9) Flow planning and traffic management,
10) Strategic clearance planning, and
11) Full tactical clearance generation and execution.

While these 11 functional improvements represent the products of the current FAA en route automation program, it must be emphasized that they do not represent the limit of ATC functional evolution. To meet the FAA mission, this evolution must continue to accommodate ongoing changes in aircraft characteristics, in technology, and in the nature of the demand for ATC services. A brief description of these eleven functional improvements is provided in the next Section II.4.2.

II.4.2 Description of the Functional Improvements

1. Conflict Alert for VFR Intruders (CA/VFR)

The CA/VFR functional improvement generates and displays to en route controllers timely warnings of potential aircraft-to-aircraft conflicts for those IFR and VFR aircraft equipped with Mode C transponders. This improvement extends the existing conflict alert function by detecting situations where VFR aircraft with Mode C transponders are moving into conflict with IFR aircraft. The current conflict alert function only warns controllers of IFR-to-IFR conflicts.

2. Conflict Resolution Advisories (CRA)

The CRA functional improvement generates and displays timely advisories to en route controllers of feasible resolutions to the conflict identified by the Conflict Alert function. Currently, all conflict resolutions are manually generated by the controllers observing and extrapolating the traffic situation on their displays and the information contained on flight strips.

3. En Route Metering (ERM)

The ERM functional improvement generates and displays metering advisories to en route flow controllers to assist them in managing the flow of traffic into congested terminals in a fuel-efficient manner. This function will not automatically coordinate with adjacent facilities and has a limited capability to adapt to changes in airport conditions such as runway reversals and closures.

4. Electronic Tabular Display Capability in Sector Suite Interface

Flight plan information is now provided to the controller via paper flight strips printed by the en route computer system. In the next generation controller station (sector suite), this information will be presented to the controller on a graphic display and the controller's flight strip handling and manipulation task will be automated. This functional improvement to the system will permit rapid and accurate electronic manipulation of flight information. To allow continued use of this electronic tabular display function, when the main computer complex fails, the new sector suite will contain a fail operational mode. The current electronic tabular display research and development program will provide the necessary inputs to the specification of this functional improvement for the next generation sector suite.

5. Advanced Surveillance Sensor System (Mode S) Interface

The Mode S interface functional improvement permits automatic exchange of information between terminals and en route surveillance sites and the en route control facility. The surveillance interface permits use of more accurate surveillance information than that of the ATCRBS system.

6. Central Weather Service Unit (CWSU) Interface

The CWSU interface functional improvement permits the display of severe weather contours at controller work stations when this information is available from the CWSU computer. The CWSU computer has the capability to process weather data from a variety of sources, generate a consistent picture for air traffic control use, and then distribute this information to controllers in a timely manner.

7. Terminal Information Display System (TIDS) Interface

The next generation sector suite in TRACONs and tower cabs will provide for the electronic display and manipulation of flight data information to replace the system of flight progress strip that are currently prepared by the host ARTCC and printed at TRACONs and tower cabs. An interface in the en route software will permit the automatic interchange of flight, weather and other ATC information between the en route computer systems and the new terminal and tower sector suites. The FAA's TIDS research and development effort will provide the necessary inputs to the design of terminal and tower versions of the new sector suite and its interface to the ARTCC.

8. Direct/Fuel Efficient Route Planning (DIRECT)

This initial far term functional improvement provides the en route system software to assist controllers in granting aircraft 'direct routing' requests. The function automates intersector route coordination, most of which is currently performed manually, and provides the en route controller with automation tools that predict aircraft densities and down-stream controller-workload for sectors impacted by the direct routing request.

9. Flow Planning and Traffic Management (Advanced En Route Metering/ERM)

The advanced ERM is a functional improvement of the en route metering described above. It permits center-level, automatically coordinated, traffic flow management. The output of this function, which uses national and terminal flow control inputs, is distributed automatically to center controllers and flow controllers and adjacent facilities. Advanced ERM is sensitive to the range of unpredictable situations that a real-time flow management system must handle.

10. Strategic Clearance Planning (Strategic AERA)

The Strategic AERA--Automated En Route ATC--functional improvement completely integrates the separate automation tools and databases to assist en route controllers in generating and delivering ATC clearance messages. The functions composing Strategic AERA, which can be selectively activated by en route controllers, generate fuel-efficient, metered and conflict-free profiles for Mode C transponder equipped aircraft operating in positively controlled airspace and the required clearance messages necessary to execute these planned profiles. Controllers review the plans and refine the required clearances and then decide whether the messages will be transmitted automatically (via datalink as an example) or by voice.

11. Full Tactical Clearance Generation and Execution (Tactical AERA). The Tactical AERA functional improvement extends Strategic AERA by implementing additional validation and automatic delivery of the computer generated clearances. At this point in ATC automation, each en route controller would actively manage significantly larger amounts of airspace and aircraft than is operationally possible in today's mostly manual system. This step requires marked increases in the en route computer system's reliability requirements.

II.4.3 Benefits of the Functional Improvements

Each of the eleven functional improvements will provide benefits toward one or more of the goals of insuring safety, promoting fuel conservation, increasing controller productivity, decreasing delay, and holding down maintenance cost. Table II-2 shows which functions contribute to each of the goals.

Safety. Safety is compromised when system errors are made that lead to a violation of the separation standards. System errors are largely due to poor judgment, inattention, or inappropriate clearance delivery; most of the functional improvements will tend to decrease these errors. Five of the first seven functional improvements will promote safety. Conflict Alert for VFR Intruders will increase safety by broadening the Conflict Alert capability so that it includes more of the total aircraft in the air. CA/VFR is an additional tool for detecting possible collisions. Specifically, controlled aircraft will get added collision protection against VFR aircraft. This function is especially effective in the 12,500 to 18,000 feet altitude band where all aircraft must be equipped with altitude reporting (Mode C) transponders. The Conflict Resolution Advisory function will increase safety by providing computer-generated alternatives for the maneuvering of aircraft so as to avoid potential conflicts. This function should provide more rapid and thorough analyses of complex conflict situations than could be performed manually. Therefore, the controller can do a better and safer job of resolving potential conflicts in all situations. Electronic flight plan display and manipulation reduces the chance for the controller to misplace or misinterpret flight data. By replacing the mechanical printer, which has been a source of reliability problems, electronic tabular display capability in the sector suite will provide a highly available capability contributing to the controller's improved effectiveness.

Mode S helps insure that the system has more accurate date on the location of each aircraft. The Mode S Interface will also increase safety through the use of Mode S Data Link to speed and validate air-ground ATC messages. CWSU makes available better information on weather conditions that are possible hazards through the use of tabular and graphic weather data that will be available to controllers. Later, this type of information will be used by AERA to assist pilots in avoiding hazardous weather areas.

TABLE II-2
RELATIONSHIP BETWEEN THE FUNCTIONAL
IMPROVEMENTS AND THE GOALS

	SAFETY	FUEL CONSERVATION	CONTROLLER PRODUCTIVITY	DELAY REDUCTION	MAINTENANCE COST*
NEAR-TERM					
1. CA/VFR	X				
2. CRA	X				
3. ERM		X		X	
4. Electronic Tabular Display Capability in Sector Suite	X		X		X
5. Mode S	X			X	
6. CWSU	X				X
7. TIDS	X		X		
FAR-TERM					
8. Direct Routes		X		X	
9. Flow planning		X		X	
10. Clearance Planning	X	X	X	X	
11. Clearance Generation	X	X	X	X	

*Decreased whenever 9020 hardware and/or software is replaced.

Functional improvements 10 and 11 increase safety by reducing the potential for human error as more and more duties are performed by the computer system. Strategic Clearance Planning will increase safety by removing many possibilities for human error in having various ATC duties performed by the computer system. It will provide an integrated planning capability that will not require controllers to initiate the use of the various automation tools that are available, and it will provide automatic aircraft separation assurance monitoring that will be integrated with the capability. Tactical Clearance Generation and Execution will use the computer system to perform more of the controllers' ATC work. This will further increase safety by removing additional possibilities for human error. In addition to the capabilities of Strategic Clearance Planning, it will automatically deliver clearances to properly equipped aircraft, and will automatically generate clearances to insure safe separation in case the ground system fails for any reason.

Fuel Conservation. This goal is initially promoted by ERM, which sees that unavoidable delay is absorbed in the most fuel-conservative way and that flights are spaced en route so that fuel-conservative descents can be followed. En route metering advisories to the controller will allow him to plan necessary delays in a manner that minimizes fuel consumption. In addition, major delays can be taken at higher altitude airspace where aircraft engines consume less fuel. All of the far-term functional improvements increase fuel conservation since they allow the system to respond with maximum flexibility to the needs of each flight.

Direct/Fuel-Efficient Route Planning will enhance fuel conservation by allowing the use of reduced route lengths, optimum climb and descent altitude profiles, and optimum cruising altitudes and speeds. The use of this capability will allow the controller to consider a larger number of fuel-conservative plans and expedite the determination of their acceptability. The current manual evaluation process with its multi-sector coordination problems limits the consideration of such non-standard plans.

Flow Planning and Traffic Management will also increase aircraft fuel conservation by making tools available to controllers that will allow the planning of conflict-free, metered, altitude/speed profiles for the flights over which they have control. It will extend the capabilities of Direct/Fuel-Conservative Planning so that: planning will be applicable to all flight plans, tentative trajectories can be checked and replanned by controllers, and each flight's conformance to its four-dimensional planning trajectory can be checked as the flight progresses.

Controller Productivity. Electronic flight data presentation and manipulation in the en route centers is an initial major contribution to controller productivity since, by automating the posting of flight strips, it gives controllers more time to focus on control of air traffic. This functional improvement will increase productivity by aiding controllers in their entry and timely assimilation of flight

and other data. It is estimated that, on average, it will reduce sector staffing by 15%. The terminal information of the next generation sector suite will increase terminal controller productivity by facilitating the flow of communications. This will be accomplished by: (1) aiding controllers in their entry and assimilation of flight and other data, (2) improving communication among the TRACON, tower cabs, and the host ARTCC, and (3) providing the ability to store locally-entered VFR flight plans. Functional improvements 10 and 11 will increase controller productivity the most as the machine takes over from the controller the planning, monitoring, and tactical control functions. Function 10 is expected to permit one man sector operation. Function 11 is expected to permit a combination of several of these "one man sectors" into a single "one man sector."

Delay. Delay is reduced initially by ERM, which schedules the aircraft en route so that they flow into the terminal area at a smooth rate. Functional improvements 8-10 will further reduce delay by allowing more aircraft to take desired routes. Today, suboptimal routes are often dictated by procedural restrictions to accommodate man-machine limitations of the ATC process. While both ground and airborne delay will be mitigated by all six functional improvements in Table II-2, the airborne component is the most significant in terms of cost savings.

Maintenance Cost. While none of these operationally functional improvements would significantly affect maintenance cost, it is expected that maintenance software and other automated maintenance techniques will be added in the future which will aid in reducing maintenance costs. The replacement of the current 9020 hardware and software, however, will significantly reduce maintenance cost.

II.5 System Requirements

The two previous sections have discussed the rising demand and the known functional evolution that an ATC computer system must be able to accommodate if the FAA is to fulfill its mission. This section describes the requirements that the ATC computer system must satisfy if the demand and functional improvements are to be dealt with successfully. These requirements are:

- capacity,
- reliability and availability,
- maintainability, and
- growth potential.

Each of these requirements will now be discussed.

Capacity. An ATC computer system must have the capacity to perform all operational functions for the aircraft being controlled. Capacity can be examined in terms of compute power, memory size, and channel capacity; the discussion here concentrates on the capacity in terms of compute power.

FAA studies have indicated that for a given level of functional capability the required compute power is proportional to the number of aircraft processed in the system.[15,16] Therefore, the processing requirements of the system are a function of the number of aircraft in the system. Figure II-1 shows how much compute power is needed for each of the functional improvements 1 to 7 as a function of traffic level; compute power is measured in terms of the amount of processing that a 9020A system (3 compute elements) can provide.

The functional improvements 8 and 9 are estimated, on a per aircraft basis, to require about twice the processing capacity as does the current system augmented with functional improvements 1 to 7. The last two functional improvements, 10 and 11, are estimated, on a per aircraft basis, to require 3 to 5 times the processing capacity as does the augmented system (functional improvements 1 to 9). To go from functional improvement 7 up to 11 will require therefore 6 to 10 times the compute power that is required at functional improvement 7. By comparing the compute power of a system to the expected demand and to the functional improvements that are expected to be implemented during the system's lifetime, one can measure the adequacy of the system's capacity.

Reliability and Availability. The 9020 systems have shown an increase in availability over the past few years. Their overall availability record has been excellent. When a 9020 system does fail as a result of hardware, software, or human problems, the controllers continue ATC operations using a backup capability called Direct Access Radar Channel (DARC). DARC supports the essential part of the current radar data processing functions of the 9020 system but none of the flight data processing functions and none of the automation aids such as conflict alert, minimum safe altitude warning, or en route metering. This backup capability is satisfactory for the current ATC operations. As more functional improvements (1-7) are added to the computer system, however, the controllers will adapt their approach for coordinating air traffic to these aids and are expected to become dependent upon those automated functions. Since these automated functions are not supported by DARC, it will become difficult for controllers to handle the air traffic with only DARC (or any other backup system that provides only RDP) during backup situations. Therefore, it is important to increase the availability of the primary computer system so that the duration of an interruption to its operation is so short that these interruptions are not apparent to the controllers. In this context, an RDP backup channel would still provide a backup capability for catastrophic failures of the primary computer system.

The need for a higher level of reliability becomes particularly critical, however, as functional improvements 8-11 are implemented. These are the improvements that shift the operating duties from the human controllers to the computer system. If the system fails, the workload would be too much for the human controllers to successfully pick up. This means that if there is a system failure, at a center there is no fully satisfactory backup available at the center. Therefore, system reliability (along with system accuracy) becomes of paramount importance as the functional improvements 8-11 are

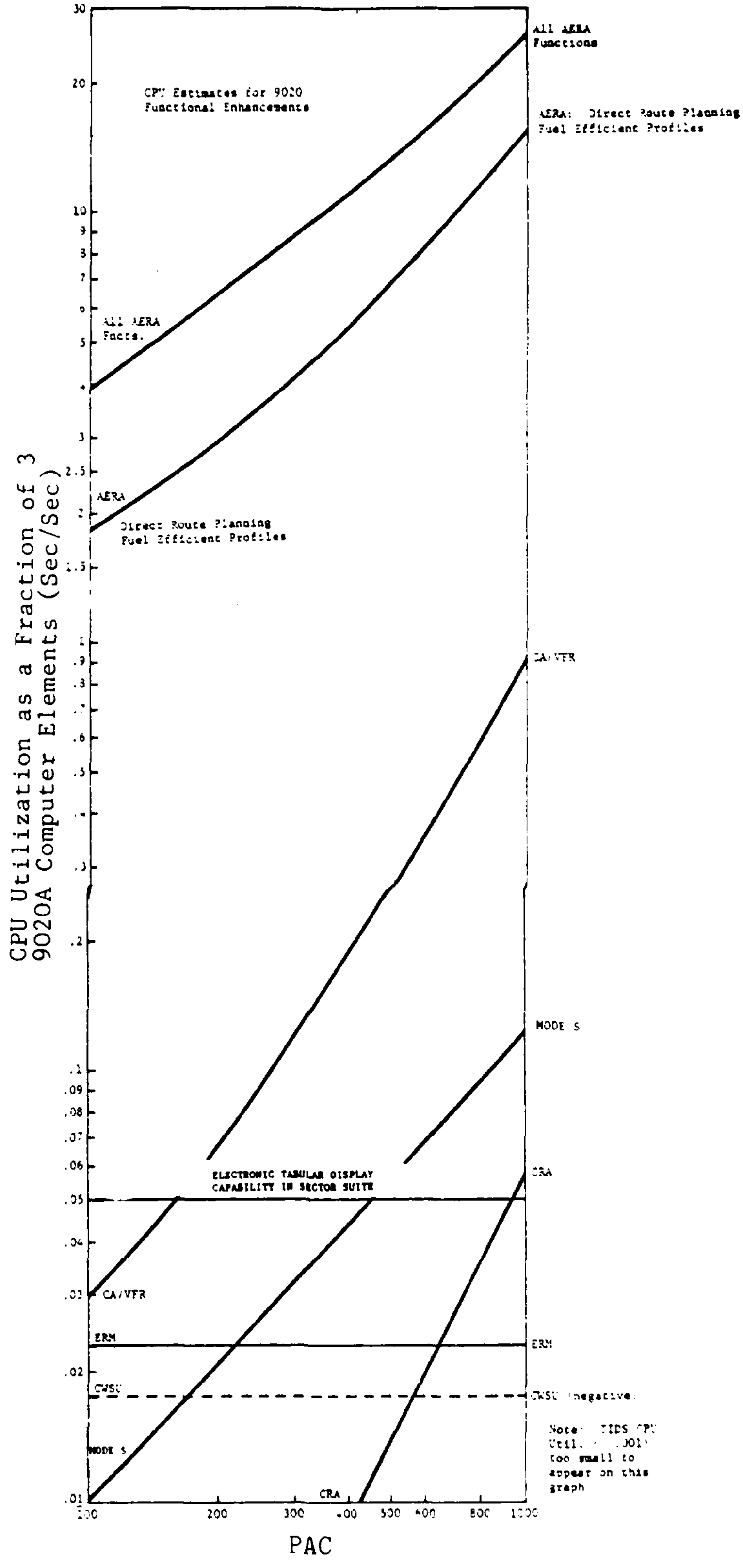


Figure II-1. CPU Estimates for 9020 Functional Enhancements

implemented and advanced automation concepts become operational. A system availability approaching 1.0 is required in the system at each center when the functional improvements are implemented. When clearances are generated by the computer, system reliability must be such that no incorrect (and potentially unsafe) clearance is ever issued. No matter how carefully a system is designed, there will still be occasional rare failures. To ensure continued safe ATC operation in light of such failures there will be a need for adjacent facilities (centers and terminals) to take over control of the airspace of the failed center.

Maintainability. Because maintenance represents a significant percentage of the system's life cycle cost, it is important to have a system that is inherently easy to maintain. Ease of maintenance is also one of the keys to high system availability. To achieve this both hardware and software must satisfy certain requirements.

In the hardware area, parts must be highly reliable to minimize the needed replacement and repair work. The number of unique parts must be kept to an absolute minimum. The hardware should contain built-in diagnostics and self-checking and reporting capabilities. Finally, it is important in the selection of systems with long life cycles to insure parts availability.

In the software area, modern techniques of programming such as top-down design and structured programming should be used to ensure that the software is modular and can be easily modified as necessary. Second, the software should be fully documented using the techniques of configuration management, which has the goal of keeping the documentation current as the software is modified. Third, support software is necessary to aid in diagnostics and testing and to monitor system performance. A model of the system is needed so that proposed modifications to the system can be designed and evaluated.

If the hardware and software satisfy these requirements, then the system can be said to be maintainable, the maintenance costs should be significantly lower than at present, and the contribution to overall system availability significantly increased.

Growth Potential. Because of the cost, potential disruption, and technical difficulties involved in making the transition between ATC computer systems, a requirement that any new system must satisfy is that it have a long life. To meet this requirement it is necessary that the computer system be able to evolve with changes in the rest of the ATC system, with changes in the functions performed by ATC, and with changes in technology so that it does not needlessly constrain the ATC system of the future.

The ATC computer system must be able to adapt to changes in the total ATC environment. The computer system is only one part of a much larger integrated ATC system that changes continuously. The

computer system must reliably accommodate, at a reasonable cost, changes in surveillance systems, communications, weather information, navigation aids, avionics, and aircraft characteristics.

The computer system must grow to support new functions. It is required that the system have resources (e.g., processing capacity, memory size) and a structure that facilitates future evolution. Moreover, the software must be modular and easily modified so that functions can be changed or added without undue effort or reliability degradation.

The computer system must also have the potential to evolve along with new technology. Because of the long system life, it is expected that there will be major advances in technology, and it is required that the computer system be capable of incorporating or taking advantage of this new technology. In this way, system capabilities can be kept ahead of needs, maintenance cost can be held down, reliability can be maintained or improved, and, most important, the need for future wholesale replacement of the computer system can be avoided. Wholesale replacement of an ATC computer system represents a major disruption of ATC service. As the ATC process puts more and more dependence on the computer, such disruption becomes less and less tolerable. Therefore, a system architecture that permits evolutionary upgrades in manageable pieces is required.

In sum, to avoid unnecessary constraints on the ATC system of the future, it is necessary that the ATC computer system be able to accommodate system, functional, and technological growth.

II.6 Summary

This chapter has developed the requirements that an en route ATC computing system must satisfy in order to meet the FAA's missions of providing safe and efficient ATC services in the context of increasing demand and evolution of the ATC system. The mission can be satisfied by meeting the goals of ensuring continued high levels of safety, promoting fuel efficiency, increasing controller productivity, avoiding delay, and holding down maintenance costs.

A number of near and far term functional improvements that will support these goals have been identified. The thrust of this functional evolution is to place increasing reliance on the computer by moving functions from the domain of the controller to the domain of the automation system. Each function provides benefits towards one or more of the five goals. Finally, the specific computer requirements for capacity, reliability and availability, maintainability, and growth potential necessary to meet demand and to support a smooth evolution of the total ATC system were identified.

III.0 ASSESSMENT OF THE CURRENT SYSTEM

This chapter reviews the current system to define the base from which the ATC system of the future will evolve. It examines the current capacity problems that exist at en route centers and the actions that are being taken to resolve the problems. It also identifies the future capacity requirements resulting from traffic growth and functional enhancement and examines the alternatives for expanding the current system to satisfy these requirements. It concludes that, because of various hardware and software limitations, the current system is not a suitable base for ATC system evolution.

III.1 Description of the Current System

The computer system at an en route center is composed of the Central Computer Complex (CCC) and the Display Channel. Figure III-1 shows a block diagram of the current system. The CCC accepts two kinds of data. Radar data comes from radar sites, yielding information about an aircraft's position and, if the aircraft is properly equipped, about its altitude. Flight data comes from flight service stations, controllers, and other sources, and contains information about the pilot's intended route of flight, the aircraft type, and other items. The CCC converts flight data into a form useful to each sector controller and sends it to the appropriate sector. The CCC also processes radar data, pairing radar returns with flight identities, and passes it to the Display Channel. The Display Channel accepts the output from the CCC and plots the radar data on the controller's Plan View Display. The controller uses the data to expedite the flow of air traffic while ensuring adequate separation of aircraft.

Figure III-1 also shows the Direct Access Radar Channel (DARC). DARC was developed as an independent backup channel to display radar information to the controller if either the CCC or the Display Channel should fail. Currently, DARC can perform only the most essential radar data processing (RDP) functions. FAA is developing enhancements to DARC that will allow it to perform nearly all of the radar data processing functions of the CCC and Display Channel.

III.1.1 Structure of the CCC

The equipment in use at each en route center varies with the air traffic volume handled by the center. Two types of CCC exist. The ten centers with the heaviest traffic use an IBM 9020D computer as the CCC. The other ten employ an IBM 9020A computer which is similar but less powerful. Centers also differ in their Display Channel equipment. The five largest centers are equipped with IBM 9020E computers; the rest use a less powerful Raytheon Computer Display Channel (CDC) to perform the display tasks.

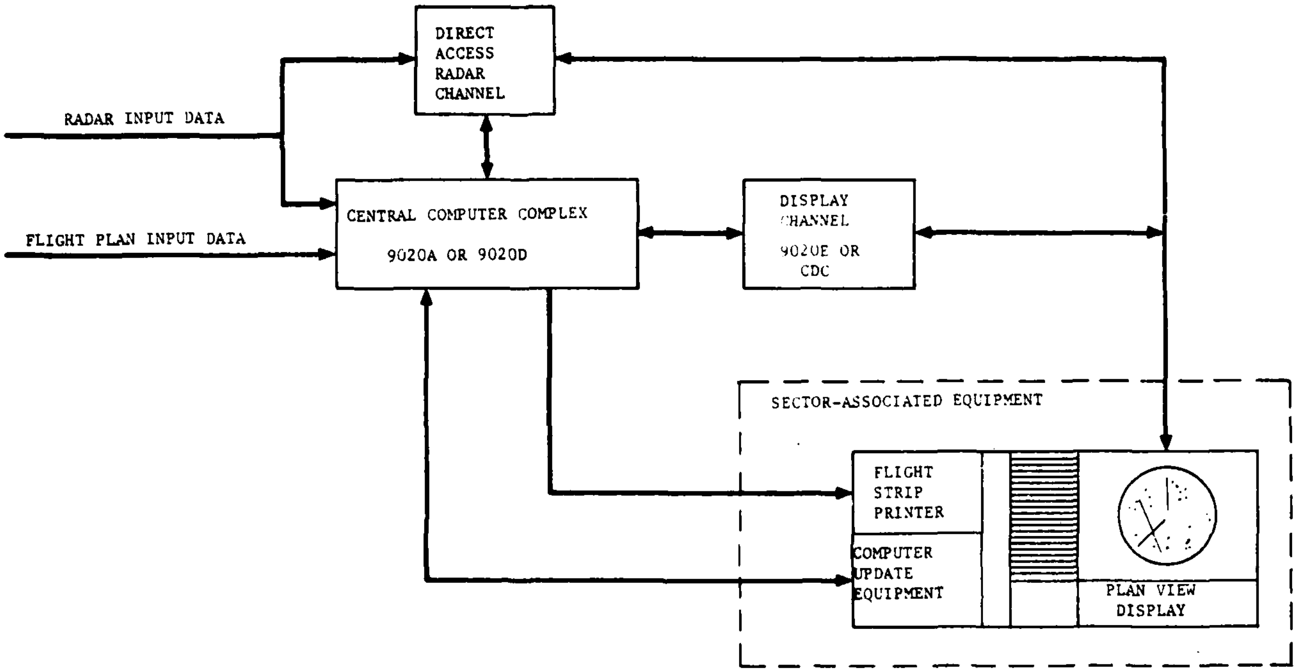


Figure III-1. Current En Route Center Computer System

Figure III-2 presents a block diagram of a 9020A CCC. The blocks at the top represent the Compute Elements (CE), that perform most of the data processing operations. They are based on IBM model 360/50 processors, adapted to operate in a reconfigurable multiprocessing system. The adaptations include special control registers, interfaces to other 9020 elements, and special instructions that are not part of the System/360 instruction set. Three computer elements are employed to handle the processing load. A fourth is supplied as a substitute to be switched in if one of the three operational processors fails; when not needed it can be used to perform non-critical processing tasks not related to immediate air traffic control problems.

Below the CEs are shown the system memory elements, known as Storage Elements (SE). The SE is a System/360 core memory module adapted for use in a reconfigurable multiprocessing system.

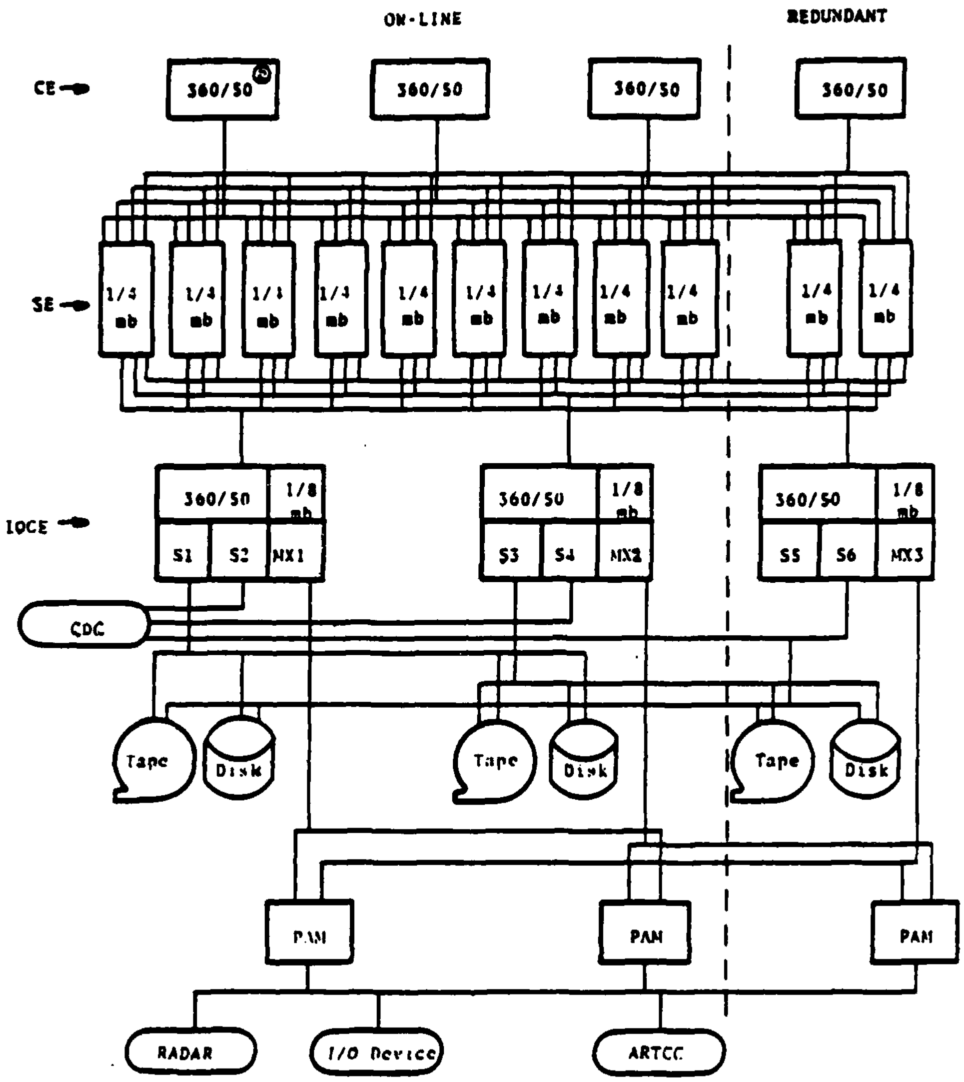
In order to free the CE's from jobs associated with input and output data processing, the system employs three converted 360/50 processors as Input-Output Control Elements (IOCE). The IOCEs perform all input and output management, and also are assigned some time-critical, input processing of the radar data. In addition to the modifications required as part of a multiprocessing system, each IOCE is equipped with 250 kilobytes of local memory.

The Peripheral Adapter Modules (PAM) shown at the bottom of the diagram provide connections to the large variety of input and output devices that connect to the CCC.

Figure III-3 illustrates the more powerful 9020D CCC. Its basic structure is similar to the 9020A, and it employs identical IOCEs and PAMs. However, the *Compute Element* in a 9020D is a modified IBM model 360/65 processor, and only 3 CEs are required instead of the 4 used in a 9020A. Along with its more powerful CEs, the 9020D is equipped with fewer Storage Elements of larger individual capacity and higher speed. The combined processing power of the 3 on-line CEs and 2 on-line IOCEs in a 9020A is about 790 thousand operations per second (KOPS), while the combined processing power of the 2 on-line CEs and 2 on-line IOCEs in a 9020D is 1452 KOPS. The effective computing power of both a 9020A and a 9020D system is less, however, due primarily to inefficiencies resulting from multiprocessor operations.

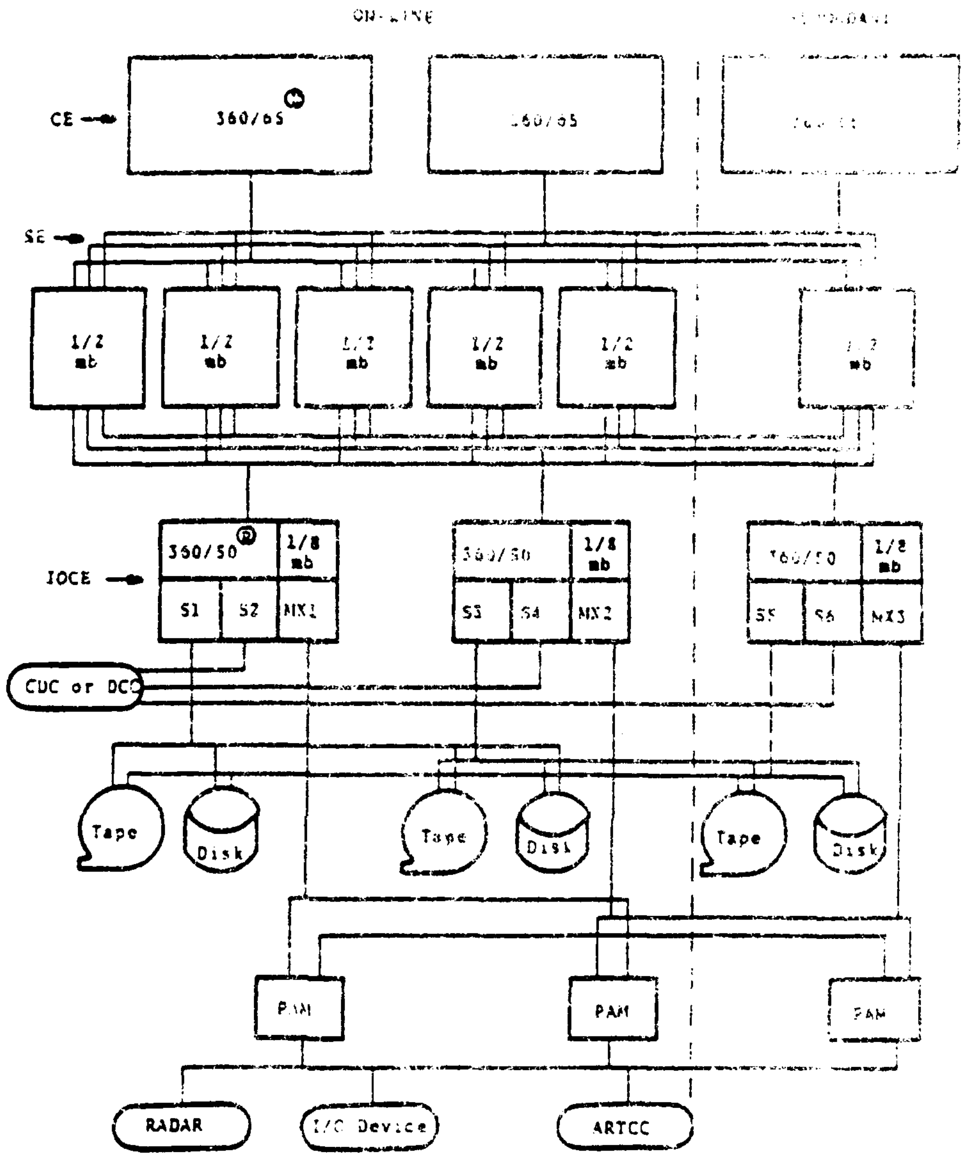
III.1.2 Special Multiprocessing Design Features

As stated above, the components of System/360 were modified to function as elements of a 9020 system. The modifications include special processor instructions, additional registers and communications buses, local storage in the IOCEs, and battery backup. Attempts to increase the 9020's capacity by installing more modern components must provide some way of adapting them to the special requirements of these 9020 features.



Si - Selector Channel
MXi - Multiplexor Channel
PAM - Peripheral Adapter Module
CDC - Display Channel

Figure III-2. Simplified 9020A Configuration Diagram



Si - Selector Channel
MXi - Multiplexor Channel
PAM - Peripheral Adapter Module
CDC/DCC - Display Channel

To implement control of the multiprocessor, special instructions were added to the standard System/360 instruction set. These instructions provide programmed configuration control, storage partitioning, system monitoring, and operational control of the multiprocessor. The 9020E was also given several special instructions that expedite the processing of graphic display data. Although these special instructions were assigned to operation codes that were unused in System/360, two of the codes have since been assigned a different purpose in System/370 and later IBM processors.

The configuration control process in the 9020 employs special registers that have been added to the CE, IOCE, and SE. These registers are loaded by means of communications buses that run from the CE to the other elements.

Some commercial equipment has been developed that conforms to the System/360 interfaces and provides more capacity, but none has the configuration registers, and special instructions. Addition of these features involves special engineering and somewhat higher cost than the standard System/360 add-on equipment.

III.2 Current System Capacity Limitations

III.2.1 Computer Capacity Problems

The problem most clearly evident in the existing ATC computer system is lack of processor capacity at 9020A sites to handle increasing traffic demand. Other potential capacity problems include channel saturation and disc and core storage resources operating at or near their capacity limits.

In the current 9020 system, memory capacity limitations and channel saturation are related. Some programs are kept on disc until required because of memory limitations. If more memory were available, all programs could be kept in the memory and the channel load (estimated at 20-30%) imposed by moving programs to and from disc (swapping) could be eliminated. If more memory were available, CPU requirements would be reduced because of reduced contention for memory access by different processors and because there would no longer be any CPU load due to moving programs to and from disc (estimated at 5-10%).

III.2.1.1 Processor Capacity

Traffic growth is the major consideration in ATC and computer system planning. As the airborne count grows, the fraction of the total computer capacity which must be utilized to support the normal ATC functions for the center's active flights increases. When the processor utilization exceeds 80%, the operation of the center is affected; system response times become unacceptably long. Continued operation under these conditions requires turning off the recording and training simulation functions. A day on which utilization exceeds 80% of capacity for 7 minutes is called an operational impact day.

air traffic delays result with continued high processor [illegible] levels. An <u>operational delay day</u> is defined to be a day during which the processor utilization exceeds 80% for a sustained period of greater than one-hour after all non-operational functions (e.g., data recording and controller training) have been turned off. Increase of the processor utilization beyond 80% results in slower output of necessary data to Air Traffic Controllers by the automation system. The Air Traffic Controllers restrict their requests to the automation system to essential services only, and increase aircraft separation in order to continue to assure safety. In cases of a sustained period of computer overload, rerouting of en route aircraft around overloaded centers, or imposition of departure delays are used to restrict traffic to managable load levels. An operational delay day, then, is a day when the [illegible] System imposes air traffic delays on users because of system loading.

A study was performed during the last half of 1980 on versions 3d2.9 and 3d2.10 of the NAS software. It translated current traffic forecast data (as presented in Chapter II) into operational delay days.[17] This study was based on the results of a recent FAA effort to measure the performance of the 9020 computer system at all twenty ARTCC's.[18,19] The results of the study are shown in Table III-1. The results represent "baseline data" in the sense that they forecast the advent of operational delay days assuming no changes (hardware or software) to the existing system. It should be noted that five 9020A sites - Oakland, Denver, Albuquerque, Houston, and Miami - are expected to have considerably degraded performance within the next 2 to 5 years, given that no action is taken. Improvements described in Section III.2.2.2 which have been implemented since that time have provided further capacity and operational delay day reductions as shown in Table III-2.

III.2.1.2 Other Capacity Constraints

The communications channels of the 9020, connect the processor to its tape and disc storage units and to all interface devices. When channel utilization exceeds 45%, the I/O subsystem introduces system delays and response times increase. An analysis of channel capacity of the 9020 is underway, but results are not yet available.

The channel capacity limitation is one aspect of a program buffering problem that also involves the core memory size and the disc memory transfer rate. As indicated earlier, if the memory could be made large enough, swapping would not be needed, and channel utilization would be less. If the disc transfer rate were faster, the channels would not be tied up so long and the I/O subsystem would not saturate so readily. Thus, at present, the other major capacity constraints are all related to limitations in the size of main memory.

FORECAST YEAR

CENTER	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1992	1994	1995
ALBUQUERQUE	2	5	24	48	104	141	178	205	223	230	233	236	238	240
ATLANTA	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BOSTON	–	–	–	–	–	–	2	4	6	11	21	30	48	56
CHICAGO	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CLEVLEAND	–	–	–	–	–	–	–	–	–	–	–	–	–	–
DENVER	31	77	152	218	264	291	313	331	342	351	355	359	365	265
FORT WORTH	–	–	–	–	–	–	–	–	–	–	–	–	–	–
HOUSTON	39	68	114	169	214	237	247	252	257	262	273	238	302	316
INDIANAPOLIS	–	–	–	–	–	–	–	–	–	–	–	–	–	–
JACKSONVILLE	–	–	–	–	–	–	–	–	–	–	–	–	–	–
KANSAS CITY	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LOS ANGELES	–	–	–	–	–	–	–	–	–	–	–	–	–	2
MIAMI	13	36	78	126	186	230	279	311	338	349	357	365	365	365
MEMPHIS	–	–	–	2	16	45	99	152	194	211	228	237	242	245
MINNEAPOLIS	–	–	2	8	26	51	90	147	192	218	240	250	258	267
NEW YORK	–	–	–	–	–	–	–	–	–	–	–	–	–	–
OAKLAND	42	70	100	140	173	193	211	227	241	243	246	249	252	254
SALT LAKE CITY	–	–	–	–	–	–	–	2	5	14	29	46	61	89
SEATTLE	–	–	–	–	7	30	64	105	142	164	186	217	234	245
WASHINGTON	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Based on NAS Software Version 3d2.9 and 3d2.10
June 1980 to Jaunary 1981

TABLE III-1 OPERATIONAL DELAY DAYS

FORECAST YEAR

CENTER	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
ALBUQUERQUE	–	–	–	–	–	–	–	–	2	2	2	2	14	28
ATLANTA	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BOSTON	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CHICAGO	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CLEVLEAND	–	–	–	–	–	–	–	–	–	–	–	–	–	–
DENVER	–	–	–	–	2	5	19	39	85	139	198	235	263	239
FORT WORTH	–	–	–	–	–	–	–	–	–	–	–	–	–	–
HOUSTON	–	–	–	–	8	21	47	75	124	160	196	225	242	248
INDIANAPOLIS	–	–	–	–	–	–	–	–	–	–	–	–	–	–
JACKSONVILE	–	–	–	–	–	–	–	–	–	–	–	–	–	–
KANSAS CITY	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LOS ANGELES	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MIAMI	–	–	–	–	–	4	11	24	60	90	127	171	214	261
MEMPHIS	–	–	–	–	–	–	–	–	–	–	2	12	25	57
MINNEAPOLIS	–	–	–	–	–	–	–	–	2	2	8	26	48	81
NEW YORK	–	–	–	–	–	–	–	–	–	–	–	–	–	–
OAKLAND	–	–	–	–	–	–	2	2	21	29	43	69	96	119
SALT LAKE CITY	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SEATTLE	–	–	–	–	–	–	–	–	–	–	2	7	24	[illegible]
WASHINGTON	–	–	–	–	–	–	–	–	–	–	–	–	–	

III.2.2 Possible Solutions

Since the beginning of its development, the NAS system has witnessed an almost continuous expansion in functional capabilities. New and/or expanded functional capability usually require additional computer resources, however. If resources are not expanded as functional capability is increased, system performance, as measured by response times, will degrade. For this reason, the software design and equipment configuration have been modified over time to bring the capacity in line with the requirements. To date, the FAA has been quite successful in bringing about a balance. The cost in terms of additional software and hardware complexity has been significant, however. The end result is a system that is difficult to maintain and one that is increasingly more difficult to expand to affect a balance.

III.2.2.1 Hardware Solutions

The major elements of a 9020 that are currently experiencing capacity problems have reached or are close to reaching their limit of expansibility. This is especially true for the most critical elements.

The 9020 (A or D) can have a maximum of 4 Compute Elements (CE's). All 9020A sites are currently configured with the maximum of 4 CE's; all 9020D sites are configured with 3 CE's. Thus, the 9020A sites, where additional processing capacity is needed the most, have reached the limit and, although 9020D sites could be expanded further, there is no need, given forecast traffic loads.

As discussed above, the required channel capacity is a function of the main memory size and rate at which data and programs must be transferred back and forth to disc storage. The addition of another I/O channel has been suggested to relieve the current problem. Each site currently has three IOCE's, which is the maximum number for the 9020 system. Each IOCE has two selector channels. A third selector channel could be added, but because of addressing contraints it could only be added to two of the three IOCE's. If this were done, the same level of redundancy that exists today could not be maintained. A limited experiment has been performed to determine the effect of adding a third selector channel to a 9020.[20] The results show only marginal improvement in I/O throughput at nominal track loads and some improvement in response times at track loads that exceed the maximum specified load. For these reasons, another selector channel is not judged to be a viable solution for potential channel capacity problems.

The model 2314 disc units in the existing system pose transfer problems. Faster disc files would reduce the time required to transfer programs and data into main memory, and would help reduce channel occupancy. Larger, faster disc units have been developed for System 370, but most current IBM-compatible discs require connection to a block multiplexor channel, which the IOCEs do not and cannot have within reasonable cost.

The 9020A sites are nearing the limits of their core memory complement using the standard 9020A storage elements. The system has needed more core memory for some time, and extensive use is already being made of program swapping, which consume system time. The 9020A design can only accept 12 SEs. All 9020A sites are equipped with 11 SEs and are in the process of being upgraded to 12 SE's*. Addition of memory beyond these design limits requires some special hardware development and engineering.

III.2.2.2 Current Initiatives

The most recent set of capacity-related changes approved for implementation results from several studies performed over the past five years. As is true of previous changes, they are intended to relieve present capacity problems. The resource recovery and expansion efforts that are currently in process or recently completed are discussed below. The estimated net effect of implementing all of these changes will be to increase the processing capacity available at sites equipped with 9020A computer systems by 30%. The changes identified below are also summarized in Table III-3.

The estimated benefit of implementing these changes is high (primarily as a result of IOCE Offloading). Resource recovery efforts will continue, the results of future efforts are expected to be smaller, however.

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*The baseline data on which the delay day analysis is based was collected when only 11 SE's were available at the 9020A sites.

TABLE III-3

Summary Of Current Initiatives

ITEM	ESTIMATED RECOVERY*	EXPECTED AVAILABLE DATE
Additional Storage	2-5%	1982
Direct Route Processor	3-7%	1981
Data Base Redesign	5-15%	1981
IOCE Offloading	10-20%	1981
Data Recording	5-15%	1982

* as a percent of a 9020A computer system (3 Compute Elements)

Additional Storage Element

The FAA is in the process of increasing the amount of main storage available at each center. One 256K byte storage element is being added to each 9020A site and one 512K byte storage element is being added to each 9020D site. With the addition of one element, all 9020A sites will reach their maximum storage capacity using the standard 9020A storage elements (3.1 Mbytes); 9020D sites will reach 70% of their maximum capacity (5.1 Mbytes). The additional storage will be used to expand the buffer area and/or move some of the programs that are currently being buffered into main memory (see Section III.2.1.2). The hardware augmentation has been completed at all 9020A sites and is near completion at 9020D sites. Software to make full use of the additional storage is expected to be available during 1982. A decrease in processor and channel utilization is expected.

Direct Route Processing

As the result of an audit performed at the Memphis Center, it was determined that a fairly large portion of the time spent in flight plan processing (about 25-30% of the total system) was taken up handling flight plans filing direct route segments. It was estimated that a significant portion (80%) of this could be saved by redesigning and recoding the program modules that perform the direct route processing function. The program changes to implement this redesign are expected to be available for delivery during 1981. The new version of direct route processing is estimated to result in a reduction in the amount of processing capacity required for flight plan processing. The total reduction will depend, however, on the portion of flights filing direct route segment, which varies from center to center.

Data Base Redesign

As the result of a study of NAS response times, it was determined that the prestored design limit of various data tables was not optimum. It was also determined that a reduction in channel and computer usage could be gained if the design could be established as a function of expected usage. Guidelines on how to determine the design limits of selected data tables in a more optimum fashion were prepared and issued in the fall of 1980.

IOCE Offloading

A number of studies[21, 22] have indicated that there is a significant amount of unused IOCE capacity (approximately 70%). An effort to redesign the NAS software to take advantage of this situation has been undertaken. The software changes are expected to be operational during 1981. The new design is expected to result in a 10-15% increase in processing capacity at the 9020A sites.

Data Recording

An earlier response time analysis study indicated that, at present, data recording is not very efficient. Several problems areas were identified, including the fact that there were duplicate and superfluous recordings. It is very important that the inefficiencies be eliminated, since up to 30% of the processing time of a 9020A system can be used supporting the data recording function. A study of data recording is in progress. It should be noted, however, that any decrease in processing that may result from improved efficiency can only be realized when the recording function is being performed and that the recording function is shut off when processing loads exceed 80%.

III.2.2.3 Summary of Current Efforts

The current system improvement program is estimated to yield a 30% gain in available processing capacity at the 9020A sites by 1983. This will alleviate some of the near-term problem. Even with a 30% increase, however, delay days are expected to begin to occur at selected 9020A sites by the 1986/1987 time frame as shown in Table III-3, with significant delays occurring by 1990.

III.3 System Evolution

The functional requirements of NAS have changed continuously over the past ten years in order to enhance the performance of the ATC system. The functional improvements currently being considered for implementation were identified in Chapter II. Two groups of functional improvements were discussed. Functional improvements 1 through 7 represent functions that are nearing the point in their development cycle where they are ready for implementation. The more advanced functional improvements (8 through 11) are in an earlier stage of development. Both groups of functional improvements will require additional computer capacity, changes to the current NAS software configuration, and for the advanced functional improvements increased system availability. Increased capacity and reliability requirements for functional improvements 8-11 cannot be met by the existing 9020 hardware. The 9020 software probably precludes the implementation of these advanced functional improvements because the data structures are not rich enough and the software complexity makes it difficult to make significant software changes.

III.3.1 Capacity Requirements of Future Functions

All of the functional improvements discussed previously in Chapter II require increased processing capacity. From the data shown in Figure II-1, it is estimated that the first seven of these functional improvements will require about 7-10% more processing capacity at 9020A sites during the 1989 timeframe. When these additional capacity requirements are combined with near-term traffic growth requirements, a relatively large increase in processing capacity will be necessary for the 9020A system to adequately service air traffic into the early 1990's. Without such increases

in the available computing capacity of the existing system, Operational Delay Days could become a fairly regular and troublesome occurrence. If functions 1-7 are implemented and capacity of the 9020 is not augmented beyond the 30% that is expected to result from the current initiatives, 9020A sites are expected to begin experiencing Operational Delay Days in the 1985/86 timeframe. By 1989, seven sites will have delay days with three sites having more than 100 delay days.

Beyond the first seven functional improvements, the FAA plans to introduce new automation features into the ATC System (functional improvements 8-11) which will have a major impact on the efficiency and capacity of the ATC system. Large increases in computer system capacity and reliability will be required to support the new functional improvements as the ATC System becomes less labor intensive and more reliant on the computer as a major ATC System resource. In Chapter II, it was estimated that the advanced automation functional improvements (8 through 11) will require 6 to 10 times more processing capacity (on a per aircraft basis) than is required for the current system augmented with functions 1-7 and signficantly greater reliability, and, for functional improvements 10 and 11, a center backup mechanism that is estimated to require 25% or more capacity at each center. The 9020 does not possess the capacity and reliability to support these requirements.

III.3.2 Potential System Expansion

As discussed above, the possibilities of increasing the capacity of the 9020 by adding like elements to the existing configuration is limited, especially in the central processor area where the need is greatest. There are, however, other ways of augmenting the 9020 to provide additional capacity (see Chapter IV). But, does the current 9020 software and hardware architecture provide a suitable base for expansion? The 9020 hardware and software components are over 10 years old; the 9020 is reaching the point where the cost of maintaining the existing configuration is high. Addition of new functional improvements is made increasingly difficult by the complex outdated software structure. The maintenance difficulties being experienced, at present, will only get worse over time.

III.3.2.1 Software Limitations

There is evidence that the NAS software is not a suitable base for the functional improvements being considered for the future. The NAS software is over ten years old and has been modified extensively. The changes that have been implemented to date have taken their toll in terms of increased design complexity.

Modification is a natural part of the software maintenance process and occurs more or less continuously as the system is used. User requirements change over time and usually can be accommodated. This is especially true for systems, like NAS, that are large and complex. Typically what happens is that as a system is modified over time, the internal structure of the software becomes more

complex. Unless an effort is made periodically to restructure the software, the end result can be a system that must be completely replaced because changes can no longer be made cost effectively.

From the beginning of its existence, the NAS software had a complex design. Complexity was needed to take full advantage of a multiprocessing architecture and to conserve scarce processing and storage resources. Because the NAS software was developed without the benefit of modern day software engineering practices, however, the years of change have added to this complexity. The evolution of the NAS data base provides an example. The original design intermixed control information with operational data. This intermixing has grown with time. NAS data tables also contain data that is used and/or modified by many functions.

When software reaches an advanced state of complexity, it is often described as being convoluted. This means that the paths through the software are no longer simple and straight-forward. This includes the paths of instruction execution within a module, the paths of communication between modules, and the paths of access through the data base. This complexity manifests itself in the so called "ripple effect," where a change to one part of the system causes new problems in apparently unrelated parts. As a result, the software becomes increasingly difficult to modify.

There is evidence that the NAS software has reached such a state. Maintenance of the NAS software has already reached the point where new problems are uncovered almost as fast as old ones are repaired. Currently each new version results in the generation of about 40 to 60 Program Trouble Reports (PTRs) after release to the field. For the most part this affects the addition of new functions, but even the removal of existing modules can become difficult because of the complex intermodule and database interfaces that exist and/or the fact that the functional responsibilities of individual modules are no longer well defined. A recent analysis of the 9020 software structure[23] has substantiated that software modification must be approached with extreme caution.

FAA examined the processing and data base requirements for functional improvements 8-11 to determine whether or not the 9020 software could reasonably support those functions. It was determined that to provide the flexibility in direct route/profile approach and more efficient metering and flow management (functional improvements 8 and 9) more extensive flight data, in the form of information about aircraft characteristics and desired profiles, is required. The conclusion of this software examination was that while some direct route and flow management improvements could be added to the 9020 software, the flight data processing programs and data structures in the 9020 software will not support addition of most of the subfunctions required for functional improvements 8 and 9. Table III-4 summarizes these findings. Functional improvements 10 and 11, which build on 8 and 9, require not only the new software structure, but also more inherent availability and higher reliability (see Chapter II) than can be provided by the current 9020 software.

FUNCTIONS	9020 SOFTWARE EXTENSIONS	NEW SOFTWARE REQUIRED
ROUTES/PROFILES		
MORE DIRECTS	X	
ARBITRARY DIRECTS		X
SECTOR/SECTOR COORDINATION		X
3-D DEPARTURE PROFILES		X
CONFLICT FREE PROFILES		X
METERING/FLOW MANAGEMENT		
METERING IMPROVEMENTS (W/COMPUTED WINDS ALOFT)	X	
CONFLICT FREE METERING		X
FLOW MANAGEMENT INTERFACE W/CENTRAL FLOW & TERMINALS	X	
INTEGRATED FLOW MANAGEMENT (USING AIRCRAFT CHARACTERISTICS, FLIGHT MANAGEMENT COMPUTERS, FLOW MODELLING, ETC.)		X

Table III-4. Limits of Current Automation System

III.3.2.2 Hardware Limitations

The unique architecture of the NAS hardware makes expansion difficult but not impossible. Expansion of the current system should not be seriously considered as a far term solution because it cannot be expected to provide the greater availability/reliability and the order of magnitude increase in capacity. While 9020 expansion could serve as a stop gap measure to satisfy near term capacity needs, the logic of expanding the NAS computer system enough to satisfy future requirements is questionable. Concerns over the difficulty and increasing cost of 9020 hardware maintenance and the potential for age related failures also represent a serious limitation to the far term use of the 9020 system.

Sporadic failures due to aging are beginning to occur in the 9020 computers. While these problems are rare, they are generally difficult to trace and, as in the case of cables that have become brittle or connectors that have become worn, can be difficult to repair. FAA has attempted to determine where the 9020 computers lie on the "bathtub" reliability curve, but these attempts have been less than successful.

No one in the computer manufacturer/user complex has been able to successfully predict when hardware "wears out" because of the large number of variables (how the equipment was used, maintained, and the environment in which it has been operated, etc.) that affect wear out. One must conclude that while the 9020 hardware is likely to require replacement because of age-related reliability degradation, the system is performing adequately today and the exact time when replacement is required cannot be predicted precisely.

Another limitation of the existing system that will become more critical as the system becomes older is the question of spare parts availability. FAA and IBM have met and identified a total of approximately 9800 piece parts requiring review so that appropriate provisioning action may be taken. These 9800 parts fall into three categories. Approximately 4900 parts have been determined to be of satisfactory availability for 5 to 7 years. Further reviews will result in refinements to the supply process to extend the availability of these parts for another 3 to 5 years. Approximately 2100 parts have been determined by FAA/IBM to be of potential supply concern. FAA has recently signed a contract to purchase approximately 700 of these parts that are of immediate concern. Finally, approximately 2800 parts will require additional review to determine supply availability. FAA is reviewing the amount, timing, and funding requirements for stockpiling these parts. FAA plans to continue a phased approach to stockpiling parts. Determination of supply levels will be reviewed periodically.

III.4 Conclusions

This chapter has presented an assessment of the suitability of the 9020 system, both hardware and software, for meeting the capacity,

reliability, maintenance, and functional requirements of the 1980's and 1990's. The current 9020 hardware and software system cannot meet the demands due to traffic growth and functional improvements 1-7 beyond the mid 1980's. Initiatives that are underway will provide an estimated 30% additional CPU capacity at the 9020A sites. This is estimated to push the onset of delay days to the mid-to-late 1980's.

Some elements of direct, fuel efficient route planning and flow planning and traffic management (functional improvements 8 and 9) can, given adequate capacity, be implemented within the confines of the 9020 software. The full range of advanced automation requirements embodied in functional improvements 8-11 requires levels of capacity, reliability, and maintainability that cannot be met by 9020 hardware. Furthermore, the 9020 software structure does not provide a suitable base for the levels of functional improvements being considered for the late 1980's and 1990's.

Both the 9020 hardware and software represent old technology. The old hardware technology leads to high logistics cost, some maintenance problems, and eventual reliability degradation. The hardware technology of the 9020 is not suitable for capacity extensions required by far term functional evolution. Because of the complexity of the existing 9020 software, future modifications will become more and more difficult and routine maintenance and testing more costly.

The capabilities and limitations of the 9020 hardware and software, when combined with the expected increase in traffic and the planned functional improvements, establishes the requirement to replace the current computer system if FAA is to continue to provide safe and efficient ATC. Chapter V addresses the alternatives for a full replacement of the current en route automation system to satisfy the requirements that have been identified.

However, when the total replacement of hardware and software is carried out, the first new system will not be fully operational until the 1988-1990 timeframe. The en route automation plan that is ultimately adopted must provide near term capacity improvements as well as productivity gains and improved software system that will result from total system replacement. Chapter IV presents options for meeting these near term capacity needs. These options range from strictly interim steps to solutions that are integral pieces of a full replacement program.

IV. NEAR-TERM OPTIONS

IV.1 Introduction

Four options were analyzed for their suitability to satisfy the computer capacity needs through the 1980's. The major motivation was to provide the needed capacity rapidly and at a reasonable cost. Ability to support evolution to the advanced ATC automation functions was not a prerequisite in defining these options. They were chosen to provide a plausible spectrum of potential solutions to the capacity enhancement problem and to address all suggestions for near term solutions made by the Senate Appropriations Committee[24] and others. The options range from doing nothing beyond the activities already in progress to complete replacement of the 9020 computers with new computers. The options were also defined more with the 9020A systems in mind than the 9020D, since the most critical near-term problem appears to be the processing capacity shortfall forecast for a number of the 9020A centers.

Option 1, Base Option; Continue with Present System, ("Do Nothing"). The Agency under this option would undertake no activities beyond projects already in progress.

Option 2, Increase 9020 Capacity Enhancement. A variety of means to increase the capacity of the 9020 are considered under this option. Both hardware enhancements and operational changes are included. All share the characteristic of retaining the existing hardware architecture and application software.

Option 3, Offload Functions from the 9020. This option examines two alternatives for functionally splitting the 9020 ATC applications software to allow a significant piece of the software to be off-loaded from the 9020 Compute Elements (CE's) to other processors. This would relieve the 9020 CEs of an appreciable part of their processing load. This approach represents a more extensive change than option 2 since both hardware and software changes are required. The alternatives considered were replacement of part of the 9020 with more powerful processors to allow reallocation of functions within the 9020, and off-loading of some functions from the 9020 to an external system. One representative of each of these categories was chosen for analysis:

3a, IOCE Replacement. The Input/Output Control Elements of the 9020, would be replaced with current technology machines that have more processing power and larger memories. Some of the programs that now execute in the 9020 Compute Elements could then be off-loaded to execute in the new IOCEs. Significant software changes would be needed to achieve any appreciable capacity recovery under this option.[25]

3b, Prime Channel DARC. The Direct Access Radar Channel, which is a back-up system, would be expanded to take over the radar data processing functions during normal operation, thus off-loading the 9020. This sub-option is representative of off-loading radar data processing to peripheral computers.

Option 4, Replace 9020 Hardware, Keep Software. Under this option, the 9020 computers would be completely replaced by new computers chosen so that they could accommodate the 9020 software. This would permit replacement of the 9020 computers and display channel while retaining the existing 9020 software. This option is responsive to the Senate report[26] which says, on page 87, "FAA should consider procuring an interim system replacement..." Two variations on that idea were analyzed:

> 4a, Full Rehosting Activity. The interim computer system would include new peripheral equipment, to take full advantage of the latest hardware technology. The software would be upgraded to operate the new peripherals and to take advantage of other features of the new hardware.
>
> 4b, Accelerated Rehosting Activity. This sub-option would accelerate the schedule and minimize the cost of the Interim System, principally by keeping the old peripherals and limiting the software changes.

IV.2 Evaluation Criteria for the Near-Term Options

The evaluation areas established for the analysis of near-term options are:

- Capacity Augmentation
- Reliability/Availability Characteristics
- Maintainability
- Cost
- Schedule
- Risk
- Ease of Transition
- Compatibility with Far Term Requirements

The amount of capacity augmentation offered by a particular solution must by itself or in combination with other enhancements be consistent with the forecast need. Also, for the near-term, the levels of automation expected do not require improvements in the reliability and availability of the existing system. Nonetheless, any cost-effective improvements that a particular solution offers in reliability and related areas is a definite plus for that option. There can be no negative impact on the reliability of the existing system if a particular modification is to be considered acceptable.

Cost is an important factor in any evaluation of alternatives where the basic requirements can be satisfied by a number of solutions. A cursory review of the potential solutions identified for the near-term problems suggests that cost is a useful discriminant in this analysis. High cost options cannot be justified unless they have a relatively long useful life. This implies that they must be considered an integral part of a full replacement option.

FAA has limited in-house resources to devote to planning, managing, and executing significant system development and implementation programs. The near-term options must be structured to minimize the FAA resources that might have to be diverted from other critical programs.

Schedule constraints are particularly significant with respect to capacity shortfall projections. The only viable near term solutions are those which can be developed and implemented in time to forestall the capacity shortfalls that are projected to occur at various ARTCCs over the next 2-4 years (Section III.2.2.3, Table III-1). Likewise, any near-term solutions that are likely to require a longer development and implementation period must also be considered in the context of system replacement options that are planned for nominally the same time period.

Each of the potential solutions for the near term problems involve modification of the existing system hardware, software, and/or procedures. To the extent that the changes may vary in level of complexity and associated risk, these factors are taken into account in the comparative analysis of the solution options.

The FAA system provides a 24 hour, 7 day-a-week service that is concerned with ensuring safety of flight in the national airspace. Consequently, any changes that are to be introduced in the system must be carefully designed and planned to avoid any significant disruption of the service. Each near-term solution option must be specifically evaluated with respect to its potential impact on air traffic control operations during the transition period in which the change is being assimilated into the ATC system.

IV.3 Assumptions and Groundrules

A number of assumptions and groundrules were established as a basis for the definition and analysis of near term options. These include general assumptions regarding the current system, acquisition groundrules, schedule groundrules, and cost assumptions. In order to put the evaluation of all the near term options on a common ground, some adjustments have been made to the schedule and cost information contained in the reports and summaries of the individual option studies.

In defining the near term options it was assumed that:

- computer capacity at 9020A sites is the most significant near term problem;

- there are no critical, near term problems with the display channel and sector suites;

- options should not constrain the implementation of electronic tabular display function in the sector suite prior to the new software;

- FAA will be able to maintain the current computer hardware and software as long as necessary for a given option; and

- FAA will proceed with the development and deployment of upgraded DARC.

For each option, the acquisition strategy that seemed to be most reasonable was selected. Schedules are based on competitive contract awards except in the special cases of 9020A to D conversion, IOCE replacement, and Prime Channel DARC where sole source awards are justifiable and could lead to faster awards.

Initial RFP dates are based on the amount of activity (specification preparation, coordination and approvals, etc.) required for a particular option. In the case of Option 2a (9020A speedup) no RFP is issued until feasibility is demonstrated. In the case of Option 3b (Prime Channel DARC) the acquisition is phased with the Upgraded DARC schedule. In all cases it is assumed that a single contractor carries out the work.

The following cost assumptions were made:

- The costs for the near term options presented in this report include cost estimates for the following cost categories: Management; Research, Development, Test, and Evaluation (RDT&E); and Investment. Management costs include FAA management and support contractor costs and are incurred throughout the system acquisition from the Requirements phase until the last system is delivered to the field. RDT&E costs are for design and development of the system and are incurred from the Requirements phase to the start of the FAA Technical Center test phase. Investment costs are the capital costs for a system. They start during the Technical Center test phase and end when the last system is delivered to the field. Investment costs include: facility modifications, initial training, initial spares, hardware acquisition and test support. These cost categories represent the nonrecurrent costs, i.e., one-time cost of the system.

- Operational and maintenance (O&M) costs, i.e., recurrent costs that are associated with the continuing operations and services performed at the centers, are not presented in this report but can be found in reference 9.

- Hardware acquisition cost for option 2b is for 10 9020D systems.

- Hardware acquisition costs for options 2a, 3a, and 4 is for 23 sites (20 operational, 2 at FAA Technical Center and 1 for the FAA Academy in Oklahoma City).

- Option 4 hardware acquisition costs have been reduced to anticipate probable reductions in cost due to technology advances. Approximately 90% of dual mainframe systems are subject to cost reductions (based on percent of cost attributed to processors and memory). The period for cost reductions extends from 1 January 1982 to the end of the appropriate design phase. Technology advances are assumed to decrease hardware costs by 7% per year.

- Software development costs are based upon FAA experience with similar type development.

- Cost estimates for special hardware and/or interfaces is based upon engineering judgment and experience with similar equipment.

- Hardware baseline costs for standard off-the-shelf items are list prices.

IV.4 Option Definition and Evaluation

IV.4.1 Base Option; Continue with Present System, ("Do Nothing") (Option 1)

This option continues en route ATC operations with the current computer sytems and displays indefinitely. No hardware or software modifications other than those that are currently in the planning or implementation stage (e.g., software optimization) are implemented. The activities now in progress and should be completed within the next year and become fully operational within two years. They work within the existing hardware and software. The initiatives, under development by the FAA's Air Traffic and Airways Facilities Services, include the addition of a storage element to the 9020 system, modifying the direct route processing and adaptation, offloading processing to the IOCE, and redesign of the internal tables (Section III.2.2.2). Although these initiatives are expected to provide a 30% CPU buyback at 9020A sites over the 1980 baseline, they cannot defer delay day onset beyond 1986/87, even if no new functions are added (see Section III.2.2.3). Option 1 initiatives therefore are not sufficient to meet the demand expected before the new computer can be in place (between 1988 and 1990) and thus additional actions are needed.

IV.4.2 Increasing 9020 Capacity (Option 2)

A number of approaches to increasing the 9020 capacity were considered. These options could be used alone or in combination with one another. The most promising, considered here for more detailed analysis, are: replace the main memory with state-of-the-art components, and speed-up the 9020A processors; replace the disks and disk controllers; and replace the 9020A compute elements with 9020D processors. The analysis performed rejects some these candidates; later in Chapter IV, a comparative evaluation of the others is provided.

IV.4.2.1 Larger and Faster Memory for the 9020

Current, solid state technology offers the opportunity to overcome, at an acceptable cost and with low technical risk, the expansion limitations of the original 9020 memory. Capacity limitations can be overcome by replacing core memory storage elements by new, solid state storage elements of larger size (doubling in size can be

readily achieved). The new SE's of 9020A's could have a significantly greater speed than the old SE's. New 9020D SE could be built to have overall performance characteristics similar to those of the old SE's. Replacement of the storage elements with larger, faster devices would increase the system throughput capacity, both by eliminating the need for buffering and by increasing the availability of the memory through a decreased memory access time. All programs and tables would be made memory resident, thus eliminating buffering. The elimination of buffering also serves to alleviate potential selector channel capacity problems, by reducing disk activity.

Faster memory on the 9020A increases overall system capacity significantly if the 9020A CE (processing element) speed is also increased. This alternative is discussed in the next section.

The memory enhancement analysis explored the possibilities of both full memory replacement and in the case of 9020D's of adding new SE's to the existing system. Because of the logistics and maintenance complications of systems that contain both old core memories and new solid state memories it was concluded that if a memory upgrade was undertaken, all of the old SE's should be replaced.

The cost of current technology memory is significantly lower than the cost of buying core memories. Development cost for this alternative is estimated at under $500,000. Individual storage elements, if procured in quantity are estimated to cost $50,000 to $100,000 per Mbyte. (A half Mbyte 9020 core technology SE costs approximately $500,000).

The state-of-the-art in memory design and production techniques make this a low risk approach from a technical, cost, and schedule view. Transition is straightforward.

Delivery of SE's could begin 15 months after contract award and memory replacement at all 20 centers completed 12 months later.

Simulation results of 9020A performance with more, faster memory show that a CPU buyback of only 10-20% is possible. For that reason, memory upgrade alone is not considered a viable alternative. It is a necessary element of the next alternative (9020A CE speedup) and could lead to a significant cost reduction for 9020A to D upgrade.

IV.4.2.2 Speed-up 9020A (Option 2a)

This option would speed up the 9020A compute element by replacing its read-only store (ROS) and internal registers, and reducing the microcycle time of the processors. To take advantage of the increase in overall processor speed, the faster (750 ns) memory described in Section IV.4.2.1 would be required. Replacement of the ROS with faster components would allow one (of five) microcycles to be deleted from the storage timing ring.

Analysis and simulation results indicate a potential CPU buyback at the 9020A sites of 50-65%. However, since the actual timing reduction that could be achieved depends on timing interactions[28], experimentation must be performed to determine the actual amount of microcycle time reduction possible. For that reason this option has a high technical risk until the buyback potential is demonstrated.

The upgrade could have a number of benefits other than the CPU speed-up. The new ROS would use less power and dissipate less heat. Parts availability problems would be minimized because a new ROS would be based on 1980's technology.

It would require approximately six to twelve months and $300,000 to prove the feasibility of this option. Assuming success at this stage, modifying each 9020A site is estimated to cost about $120,000, for a total of $1.2 million. Thus, the development and hardware acquisition cost estimated for the speed-up is about $1.5 million, with full development commencing within 3 months of the end of the feasibility study. The transition time is on the order of 12 to 18 months. The transition process requires further evaluation to determine whether processors could be upgraded one at a time or whether all processors at a facility must be modified at the same time. Figure IV-1 shows the schedule for this alternative.

The total program cost for the speed-up and the implementation of a larger and faster memory required by the speed-up (IV.4.2.1) is approximately 24M.

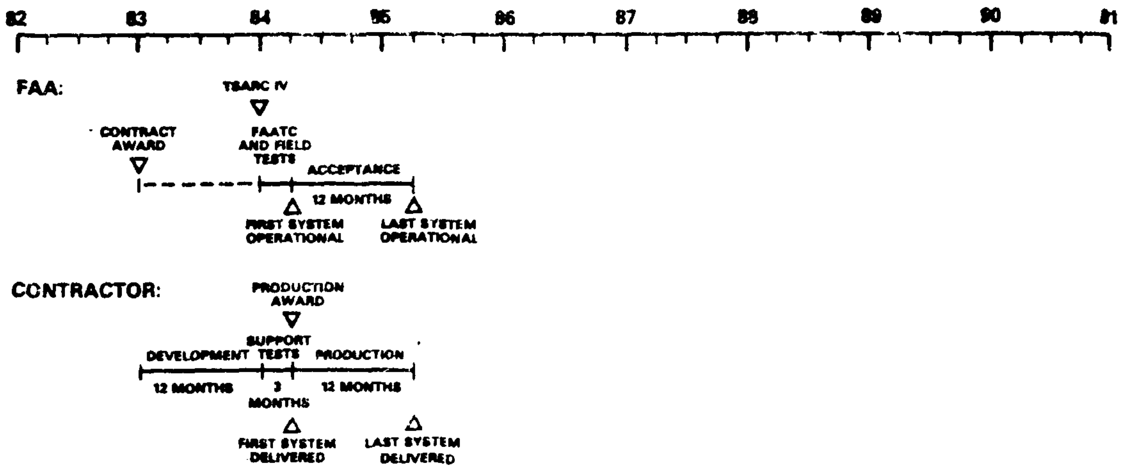
IV.4.2.3 Replace Disks and Disk Controllers

Replacement of the 2314 disk subsystems with current-technology drives would result in decreased access times and greatly increased storage capacity and data transfer rate. Device reliability might increase by as much as 90%, and the data transfer rate could increase by as much as 300% but would be limited by the IOCE memory cycle time. Since there is a potential 9020D performance limitation due to IOCE channel loading, however, it is probably not desirable to add new technology devices which have high transfer rates and thus would tend to increase the channel loading at these sites. Also, most current IBM-compatible disks require connection to a block multiplexor channel, which the IOCEs do not and cannot have; thus custom hardware interfaces would have to be developed. Finally, new software device support would have to be generated for the new devices. While the higher reliability and capacity of new disks is desirable, they offer little or no processor capacity improvement. Because of the relatively low benefit to 9020 operation and the technical difficulties associated with disk upgrading, this option is not considered further here.

IV.4.2.4 Replace 9020As with 9020Ds (Option 2b)

This option would replace the 9020A systems at the ten "A" sites with the more powerful 9020D. Since the 9020D has 2.5 times the effective computational power of the 9020A, replacing the four 9020A compute elements at a site with three 9020Ds would provide a 150% capacity buyback. Delay day onset would be postponed to 1996 (1998 if memory at all sites is expanded).

2a Speed-up 9020A



2b 9020A to 9020D Conversion

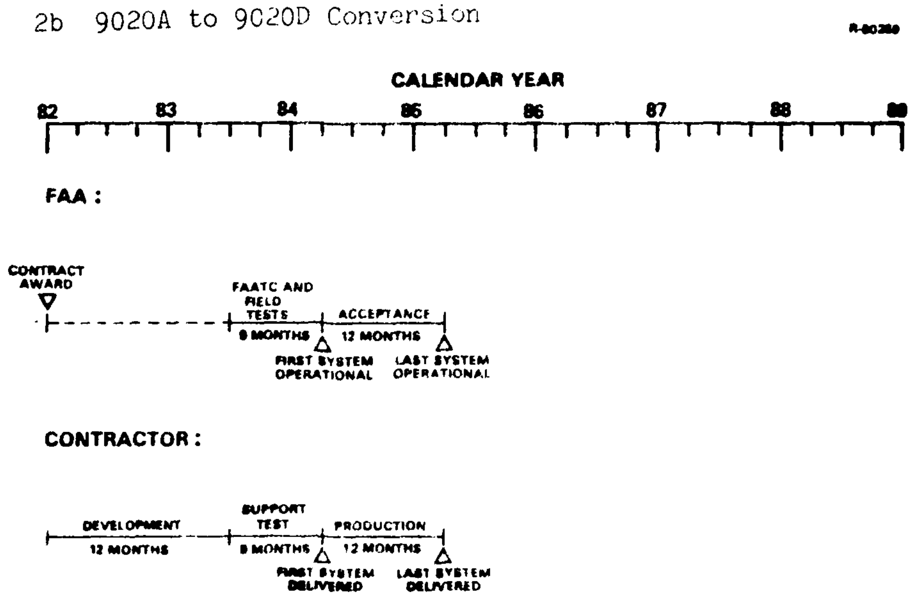


Figure IV-1. Schedule for Option 2 - Increase 9020 Capacity

Upgrading a 9020A to a 9020D involves refurbishing and modifying three 360/65 processors, obtaining 3.5 Mbytes of appropriately modified 360/65 core memory, and making some minor modification to the separate 9020 input/output control elements. FAA has already upgraded the 9020A at Jacksonville to a 9020D, so the transition process is well understood and the cost, technical, and schedule risks are low. (This does not, however, mean transition is easy or non-disruptive.) Once the sites are converted, the existing 9020 software application and support software could be used without modification. Since hardware already in the FAA inventory and existing software are used, hardware and software maintenance and logistics impacts are negligible. Availability/reliability of the system would not be affected. The first site could be converted approximately two years after a decision to proceed with a 9020A to D conversion. Conversion of all 10 sites could be accomplished over a one to two year period as shown in Figure IV-1. It is important to realize that while this approach would provide the needed capacity, the system that would result from this option would be made up of a relatively old hardware design which will retain many of the current maintenance problems. The total cost, including installation and FAA costs, is estimated at $64M for all ten sites.

Since the amount of memory in the current 9020D may represent a constraint on system operation in the 1990's, an additional system change was studied that would increase memory size at all 20 sites. An increase from 3 1/2 to 5 Mbytes of core memory could be accomplished for an additional $32M or a total cost of $96M.

An alternative acquisition strategy that could significantly reduce cost but would require some hardware development was explored. 9020D processors for the 10 9020A sites could be purchased for approximately $17 million. Instead of procuring additional 9020D core memories, 5 Mbytes of current technology solid state memory would be procured for all 20 centers. (Because of the relatively low cost of this memory and the difficulty of maintaining and providing logistics support for systems with mixed old 360 and current solid state memories, it is advisable to replace the 3.5 Mbytes of memory at each of the current 9020D sites. The use of modern high density memory components also offers the potential of increasing the amount of main memory at the 9020D sites while remaining within the ten box limit.) Some interface development and modification of "off-the-shelf" memory would be required to convert it to 9020D type memory. These modifications would require a development effort of under one-half million dollars. Although technical risk of this development is judged to be acceptable, the necessary development and upgrading with solid state memory may take a year longer to achieve than a core memory upgrade. Based on estimates from two memory manufacturers, the cost of 5 Mbytes for 20 centers is estimated between $10 million and $18 million. Under this approach, program management and installation is estimated at $2.5 million and training and spares for the new memory at $2 million for a total program cost of $32-40 million.

IV.4.2.5 Selection of Enhancements Under Option 2

Two of the most promising Option 2 enhancements are the 9020A speed-up and the 9020 A-D conversion options. The potential gain of the former is estimated to be 50-65% of a 9020A system. Replacing 9020As with 9020Ds achieves a 150% CPU buyback. The 9020A to 9020D conversion is attractive because of its low technical risk.

It must be noted that all Option 2 enhancements have similar drawbacks. They all keep the current software, and use the old technology hardware currently in place. Most of the maintenance problems associated with the current system will thus remain, and evolution to advanced automation is precluded without further replacement. Thus these options are not suitable as a far-term solution to the capacity problem, although they have some value as interim or stopgap measures.

Table IV-1 summarizes these two 9020 enhancements in terms of cost, schedule (year in which the first system becomes operational), technical risk, reliability, availability, and maintainability (R/A/M) implications and transition risk.

IV.4.3 Offloading Functions from the 9020 (Option 3)

Option 3 involves functionally splitting the NAS software and partially offloading it to a new processor. This option group is generally more complex than the preceding group because it requires more than simple additions to the 9020 equipment or replacement of isolated components. A radical equipment substitution and/or fundamental changes in the Central Computer Complex (CCC) architecture, with corresponding changes in organization of software functions would be performed.

FAA has performed an analysis of the structure of the 9020 software in order to gain a better understanding of the feasibility of functionally splitting the software.[29] The analysis showed that much of the modularity of the software has been lost over time. The different modules of the system are strongly interconnected in terms of both control flow (programs) and table usage (data). This indicates that functional splitting of software is difficult. It entails significant risk that modules that remain in the 9020 might no longer operate correctly and that errors could result from improper coordination between the modules in the 9020 and those split out of it. Recovery from errors becomes difficult. The conclusion of the analysis is that functional splitting of the software would be a large effort (the largest single change to the 9020 software that the FAA has ever attempted) with some schedule and technical risk.

	9020A CPU%	$COST	SCHEDULE	RISK	R/A/M	TRANS
REPLACE & ADD FASTER MEMORY PLUS MICROSTORE	50	12-15M	84	H/L*	+	L
REPLACE 9020A's WITH 9020D's						
5 SITES	150	32M	84	L	0	L
10 SITES	150	64M	84	L	0	L

* Technical risk becomes low after initial feasibility demonstration.

Table IV-1. Option 2, Increase 9020 Capacity Evaluation

IV.4.3.1 IOCE Replacement (Option 3a)

The Input/Output Control Element (IOCE) Replacement option requires replacement of the existing IOCE by a more powerful processor capable of executing the existing software, with a large amount of local storage, and transferring a substantial portion of the application software for execution in the replacement IOCE. Thus both the compute elements and the storage elements are offloaded. Figure IV-2A illustrates this suboption. The IOCE replacements are in bold blocks to indicate that they are new to the system. The arrows into these blocks reflect the offloading of functions to the IOCE replacement processors.

The existing IOCE is a modified IBM model 360/50 processor; a typical candidate replacement is an IBM 4341 processor that is 4-5 times as fast and can have 30 times as much main storage. The 4341 would require modification to adapt it to the 9020 communication and configuration control schemes, and the existing 9020 mass storage devices--disc drives, tape drives, and their controllers--would be replaced by current production items.

In the current system, the 9020 hardware and NAS monitor provide an operating environment for the NAS application software. In the new IOCE, part of this environment would be provided by a computer capable of implementing the existing software and supporting the 9020's special instructions. The remainder of this environment would be provided by a combination of modifications to the NAS monitor and the services provided by a virtual machine monitor, IBM's VM/370 operating system. The VM monitor, with suitable modifications, has the capability of emulating the 9020 hardware on a modern machine, thus simplifying the conversion of the NAS software to the new hardware. To the NAS monitor, operating under control of VM, it would appear that the operational hardware was a 9020 configuration. A portion of the NAS application code, in turn, would run under control of the NAS monitor. The application code selected for execution in the 4341 would be chosen to minimize table interactions, thus minimizing the number of tables which would have to be duplicated in the 9020 and the 4341, and minimizing the interprocessor communication. Some 9020 instructions are incompatible with the 4341's instruction set; these could be handled by a combination of microcode changes in the 4341 and modifications to VM/370.[30] Changes would also be required in the NAS Monitor in the areas of input/output, startup/startover, and the Operational Error Analysis Program.

Technical and Transition Feasibility. IOCE replacement appears feasible from a technical and transition viewpoint. The rehost analysis[31] indicated that 9020 software could work on current generation instruction compatible machines like the IBM 4341. No potential problems are indicated in converting a 4341 to an IOCE "look-alike." A plan which would replace one IOCE at a time appears feasible and meets the FAA's requirement to switch back to the original 9020 hardware configuration should problems arise. Once the hardware is replaced and proven with the existing software, software offloading could begin.

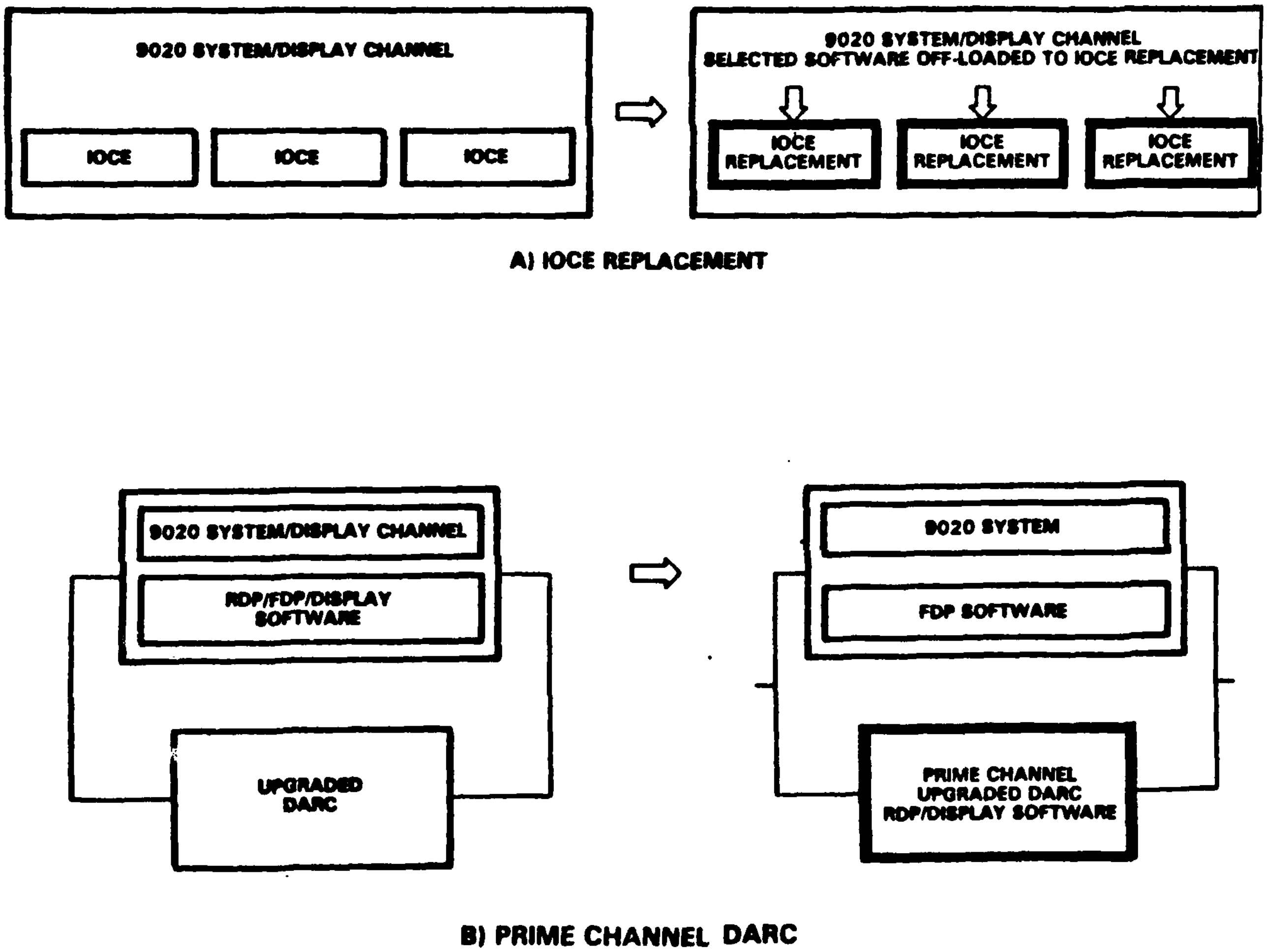


Figure IV-2 Option 3a and 3b, Offloading Functions from the 9020

The software split poses the greatest technical risk and the projection of capacity buyback presents the greatest uncertainty. Two alternatives for software split have been examined. The first and simpler alternative would offload primarily functions related to flight data processing. The second alternative which emphasizes offloading of functions related to radar processing, tracking, and display could yield a potential improvement of 40% in the 9020A, but could also involve a significant (high risk) software modification effort. This results in an additional $15M software development effort. Clearly the offloading could be extended for greater CPU buyback, but as more functions are offloaded, the risk of the approach increases. It must be noted that IOCE replacement does permit much simpler communication and coordination between 9020 functions and functions in the new IOCE than in other approaches to functional software splits because the IOCE is able to directly access tables in the 9020 main memory.

Cost and Schedule. The cost of IOCE replacement (including program management and support) is estimated at $109 million for the first alternative and at $124 million for second alternative. Schedule estimates indicate 30-36 months from start of effort to initial field site installation and approximately 50 months to completion of IOCE replacement at all ARTCC's (see Figure IV-3).

IV.4.3.2 Prime Channel DARC (Option 3b)

Prime Channel DARC is an extension of the Direct Access Radar Channel (DARC) RDP backup system, which would give DARC sufficient hardware and software capability to duplicate the RDP processing of the 9020 and display processing of the Display Channel. The existing DARC is a distributed system which was developed as a backup for the 9020 Radar Data Processing. RDP could be removed from the 9020 and the Display Channel removed from the existing computer complex. The name Prime Channel DARC reflects the fact that DARC would be the RDP system during normal operation instead of backup operation.

Prime Channel DARC is a natural extension to and assumes the existence of the planned Enhanced DARC system. Enhanced DARC is an upgrade of the existing DARC that nearly duplicates the 9020 RDP for backup purposes. The following discussion of Prime Channel DARC, including cost estimates, assumes successful implementation of Enhanced DARC. The extension to Prime Channel DARC would require some additional hardware for redundancy and software changes to both Enhanced DARC and the 9020. Figure IV-2B illustrates the two steps of this suboption. The initial portion of the figure indicates the implementation of new hardware for Enhanced DARC. The bold block associated with the second step denotes the implementation of additional new hardware for Prime Channel DARC, the off-loading of RDP modules onto the new hardware, and the removal of RDP and display processing functions from the 9020.

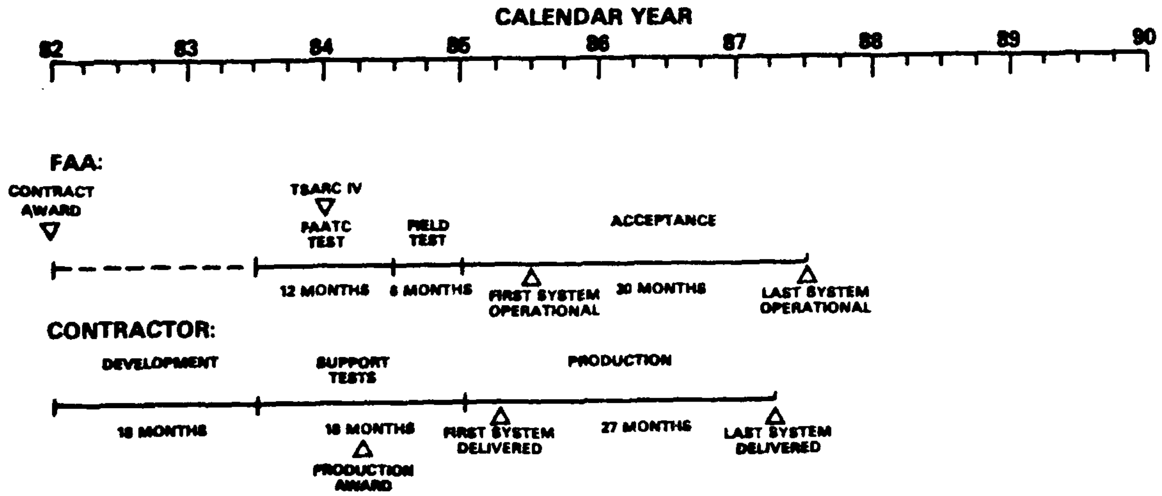


Figure IV-3. Schedule for Option 3a - Offload Functions from the 9020, IOCE Replacement

Technical and Transition Feasibility. Prime Channel DARC appears feasible from a technical and transition viewpoint. The benefits of Prime Channel DARC are a 35-40% 9020A CCC computer processing capacity buyback and, because the display channel hardware and software can be eliminated, slightly increased system reliability and lower maintenance cost. The elimination of some IOCE functions will yield a possible gain in IOCE capacity. Although the failure characteristics of the highly distributed Prime Channel DARC system make it a highly reliable system, the removal of RDP from the 9020 leaves the system without an independent RDP backup channel. Finally, the distributed nature of Prime Channel DARC will necessitate some different operational procedures in case of failure.

Hardware development and transition risks are low since the changes to Enhanced DARC are straightforward. The software risk is greater since it requires the type of 9020 software splitting described earlier. FAA has performed an extensive analysis of a specific software approach to Prime Channel DARC and has found that the split is feasible, but that significant modification of the 9020 software, involving some cost and schedule risk, is required.[32] Data base coordination between the distributed radar data processing and a necessary centralized track table can be accomplished, however, with some risk. Failure modes have been analyzed and do not appear to present a problem as long as redundant display processors can be switched into the sytem automatically. If no redundant display processors are available, there must be a mechanism for automatic assignment of tracks from the failed processor to an already active processor, so that the central track table in the 9020 can be updated for the critical conflict alert and minimum safe altitude warning functions.

Cost and Schedule. FAA has estimated a cost of $40-$45 million for Prime Channel DARC. Note that this cost assumes successful implementation of Enhanced DARC. This includes the cost of software and hardware development, system acquisition, installation, training, and FAA management. It is estimated that the first system could be installed 42 months after contract award and all the 20 en route centers could be upgraded over a one-year period (see Figure IV-4).

IV.4.4. Replace 9020 Hardware, Keep Software (Option 4)

This option would replace the 9020 Central Computer Complex with a current generation computer that could accommodate the 9020 software.

Today's IBM standard 370 product line (embodied in the 303X series) and the smaller scale 4300 product line are direct descendants of the IBM 360 architecture upon which the 9020 is based. The machine level instruction set of the System/360 is fully supported on the current generation system. FAA analysis has established[33] and FAA Technical Center experiments have demonstrated that all 9020 instructions could, with some software modification, be supported on these current generation machines. The IBM 370 and 4300 are and will continue to be industry standards. To date, three manufacturers of 370 type computers (IBM, AMDAHL, and National Semiconductor) have claimed that they could replace the 9020's with their computers and, with a minimal

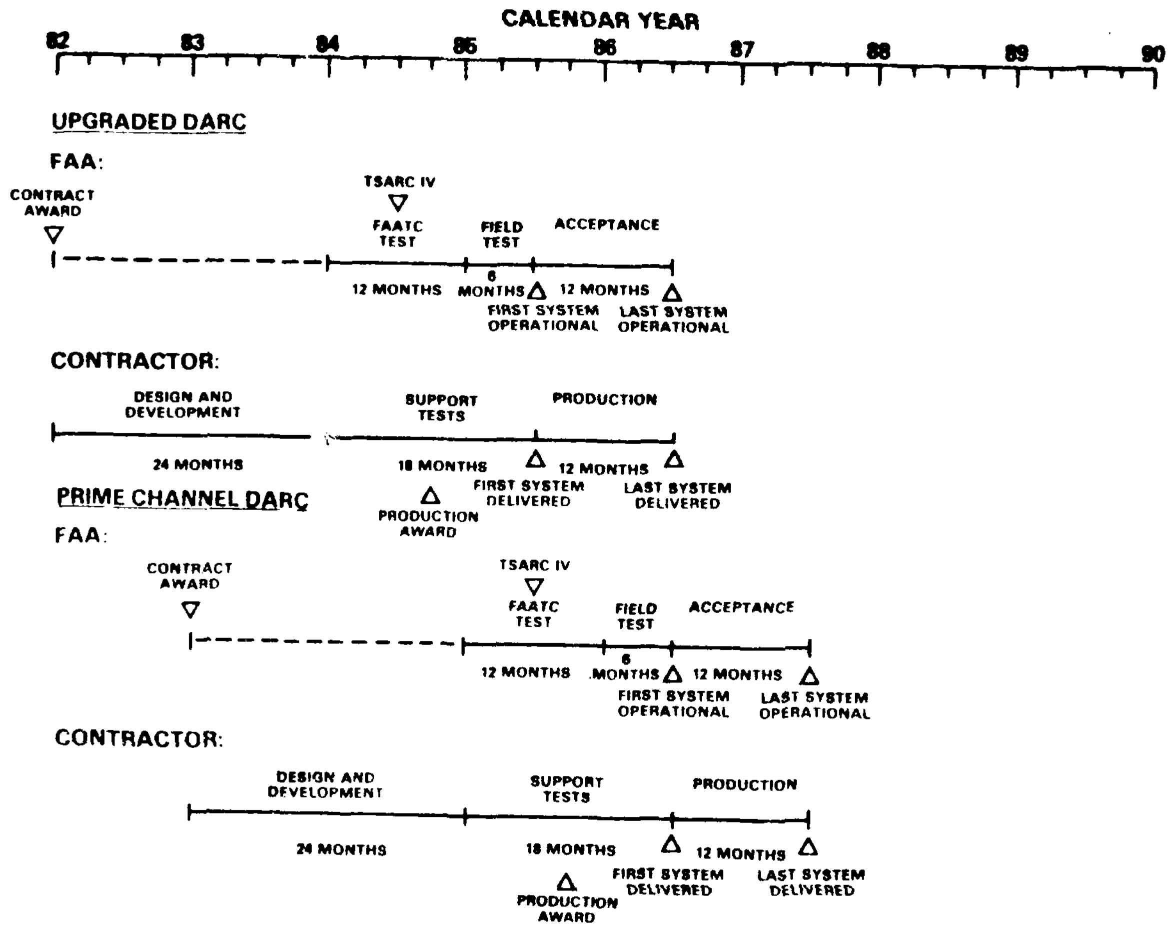
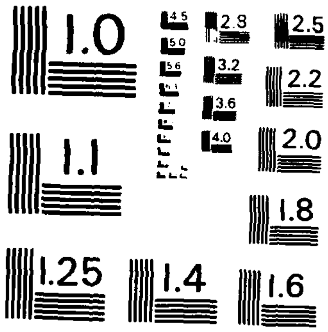


Figure IV-4. Schedule for Option 3b - Offload Functions from the 9020, Prime Channel DARC

AD-A142 045 RESPONSE TO CONGRESSIONAL RECOMMENDATIONS REGARDING THE FAA'S EN ROUTE AI..(U) FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE OF AIRPO.. JAN 82 2/3

UNCLASSIFIED DOT/FAA/AAP-82-3 F/G 17/7 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

software effort, run the existing 9020 application and support program. An extensive, independent analysis performed by FAA has substantiated the feasibility of such an approach, although at some risk and, relative to other near term capacity solutions, at considerable cost. The additional cost can be justified because the hardware, which repesents a major portion of the cost, can become part of a far term solution, while the hardware (and software) for the other near term options are throwaways.

The following discussion is based on a specific rehost approach analyzed by FAA. Several variants of the approach have been suggested by industry, but they do not significantly alter the results of the FAA technical feasibility, reliability, cost, and schedule analyses summarized here.

The full hosting activity (denoted as Option 4a) would replace the current computers (including the display channel computers), tapes, and disks. The peripheral adapter modules and the display generators would not be replaced. The heart of the host system would be two mainframes. One mainframe would handle the processing now done by the central computer complex (the 9020A or 9020D) and by the display channel; the other mainframe would be standing by ready to take over the processing if the first mainframe fails. Figure IV-5 illustrates the significant changes associated with Option 4a. This host system would use the NAS software currently used, with this software only changed insofar as necessary for it to run on the new machines. The virtual machine monitor VM would be used to provide an environment in which the 9020 monitor, the display channel monitor, and the application programs could operate. Some special hardware, a display refresh memory unit, would have to be developed to interface the new mainframe to the existing controller displays.

<u>Technical Feasibility.</u> Can the NAS software be made to run successfully on the host machines? There are three aspects to this question.

First, the 9020A's, D's and E's execute 15 special instructions that are not in the standard IBM 370 repertoire. Second, a number of features of the 9020 environment pose potential problems for the host system. These problems pertain to memory usage, timer usage and synchronization, peripheral device usage, and real-time diagnosis and error analysis. Third, the automatic reconfiguration mechanisms that make the 9020 system a high availability system must be duplicated in the new duplex system architecture so that service can be restored rapidly (5-20 seconds) in case of a hardware or software failure.

FAA has, as part of its analysis, shown that hosting is technically feasible by postulating actual solutions to these potential problems. The AMDAHL V7 (used as the cost baseline computer for this study) would provide approximately four times the raw effective capacity of a 9020D system. This assumes a significant (25-50%) overhead of operation under the virtual monitor VM. A performance analysis indicates that response time of the AMDAHL V7 would be better than the

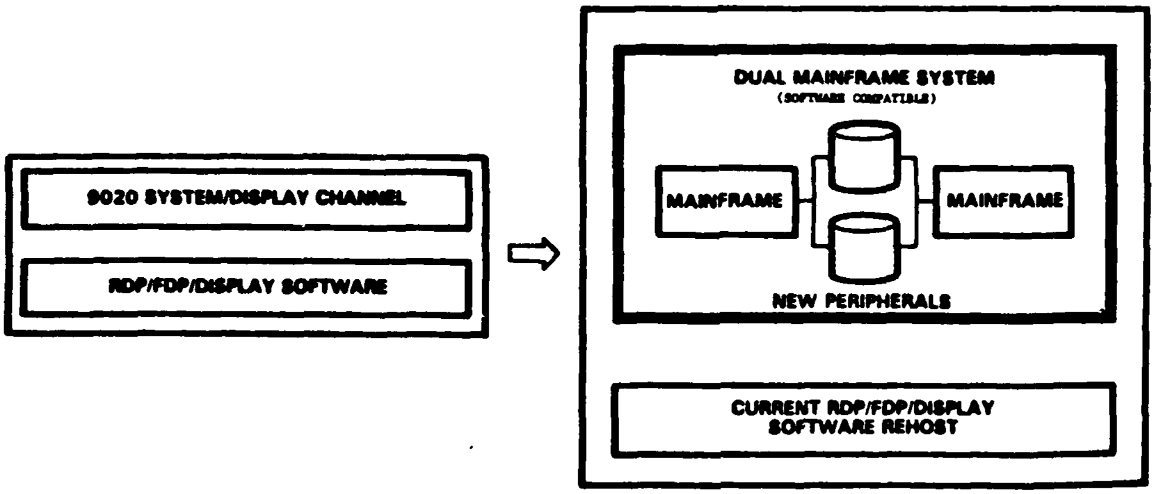


Figure IV-5. Option 4a - Replace 9020 Hardware, Keep Software, Full Rehosting Activity

current 9020 response time until well into the 1990's. Since the V7 is at the bottom end of the spectrum of 370 class machines, larger computers could be procured (at a somewhat higher cost) should that prove desirable.

Cost. The cost of the host is estimated at $252 million (1981 dollars). This includes all development, hardware acquisition, software modification, initial spares and training, transition, and FAA program management. The cost is based on use of the AMDAHL V7 computer and assumes that 23 duplex systems are procured - one for each of the 20 en route centers plus a training facility, a test facility, and a development facility. Because of the significantly lower cost of maintaining 1980's hardware than 1960's hardware an initial maintenance cost reduction of .5 million dollars is expected. This would gradually rise to an annual saving of $9 million over a five year period.

The main cost of hosting is seen to be the hardware acquisition cost, which is more than half the initial cost. Since most of the hardware acquired is off-the-shelf equipment, there is relatively little uncertainty about this cost. Because of the uniqueness of the host problem, there is some uncertainty about the administrative costs, the software cost, the spare parts cost, and the transition cost.

Schedule. Program development and implementation time is estimated to be 69 months. If an RFP is issued on 1 July 1982, the first system will be operational at an en route center on 1 April 1986, and the system will be operational at all centers on 1 April 1988. The schedule for Option 4a is summarized in Figure IV-6.

Transition. The FAA has established the requirement that when a new computer is installed, there should be no significant interruption in the seven days-a-week, twenty-four hours a day provision of air traffic control services. To accomplish this, there must be a period in which both the old and new systems are operating in a manner that allows switchover from one system to the other within seconds. FAA's analysis indicates that with some remodeling, appropriate training of personnel, and careful planning and preparation a smooth transition could be achieved.

Option 4b. A more brute force hosting approach than the one postulated for the FAA analysis could cut 12-15 months off this schedule and would reduce the program cost from $252 million to $226 million. This is achieved by making fewer software modifications at the expense of greater dependence on the virtual machine monitor and an inability to support new peripherals. Figure IV-7 illustrates that the existing peripheral equipment is interfaced with the new dual mainframe computer system. About $5 million of the cost reduction is due to less software development; the rest comes from elimination of disk and tape replacement. This approach has greater schedule risk and will result in lower reliability because of the greater dependence on the VM monitor. The schedule is summarized in Figure IV-8.

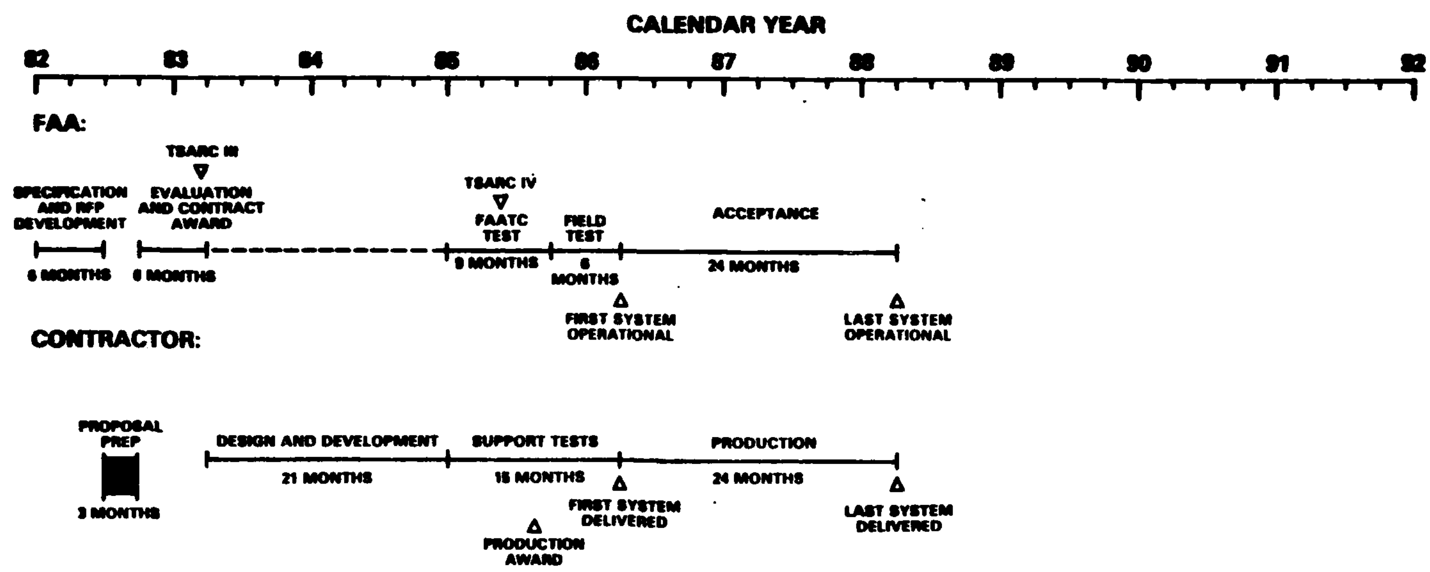


Figure IV-6. Schedule for Option 4a - Replace 9020 Hardware, Keep Software, Full Rehosting Activity

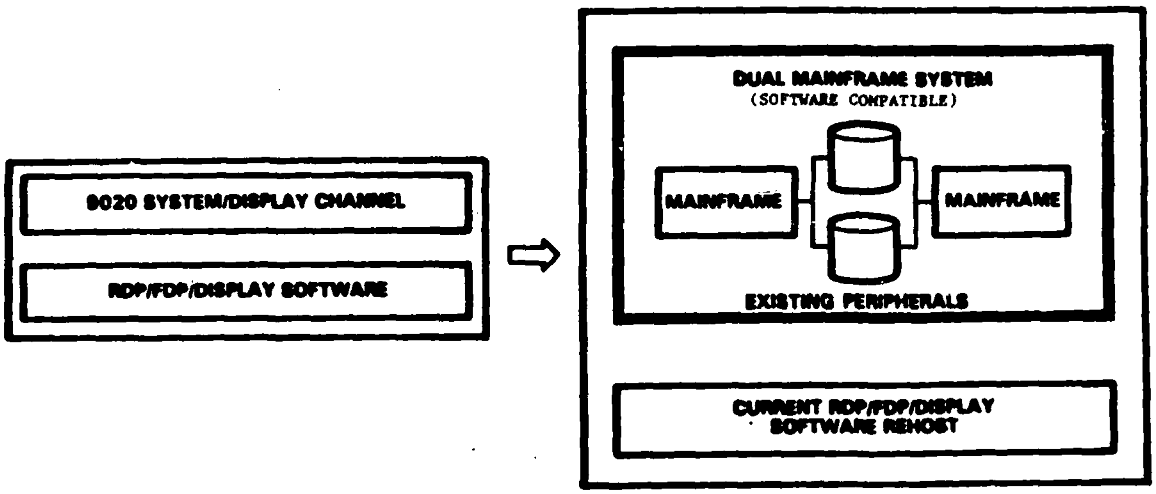


Figure IV-7. Option 4b - Replace 9020 Hardware, Keep Software, Accelerated Rehosting Activity

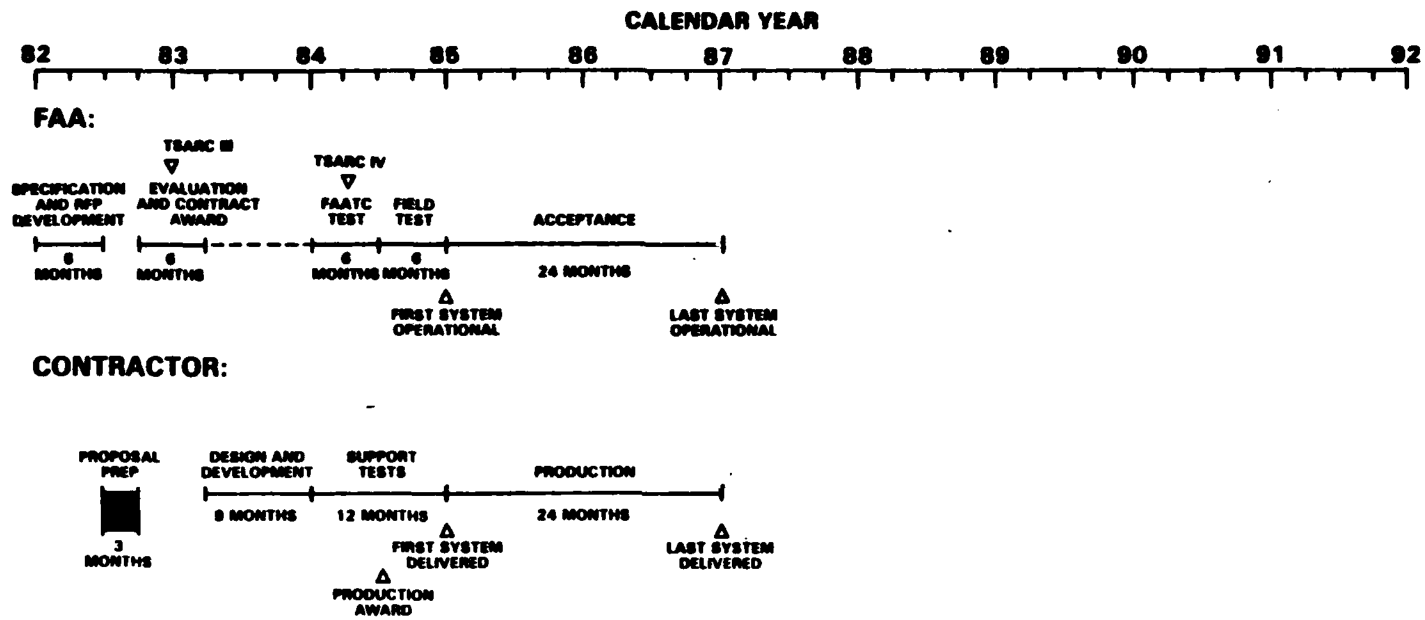


Figure IV-8. Schedule for Option 4b - Replace 9020 Hardware, Keep Software, Accelerated Rehosting Activity

Other Approaches.

As indicated earlier, options 4a and 4b are variants of a specific approach selected for analysis. There are other approaches to achieving hosting. Instead of using VM as the hosting vehicle one might modify the application code to run under the MVS operating system or rewrite the NAS monitor to run on the new computer in native mode. If early replacement of sector suites with a more intelligent, distributed display system is contemplated, it would make sense to keep the existing display channel computers and limit hosting to the central computer complex (CCC). Finally, once the host system is in place and operating smoothly, replacement of the peripheral adapter modules might be contemplated.

IV.5 Analysis of the Near Term Options

In this subsection the evaluation criteria discussed previously are applied to the near term computer enhancement options defined in the preceding subsection. The intent is to provide a comparative analysis of the options that will support the selection of one (or more) of the options for further evaluation and/or development. The option evaluation is summarized in Table IV-2.

IV.5.1 Capacity Augmentation

Each of the viable near-term options provides sufficient capacity augmentation for the 9020 system to accommodate (1) traffic growth projected through the year 1988, and (2) near-term functional enhancements programmed for implementation between now and 1988.

Specifically, with each of these near-term options, the first occurence, or year, of operational delay days will be postponed a different number of years. The table below identifies the first year that delay days occur for each of the near-term options.

Near-Term Options

	"A" to "D" Conversion		Memory and Microstore	IOCE Offload	Prime Channel DARC
	without additional memory	with additional memory			
DELAY DAY ONSET	1996	1998	1992	1991	1990

Consequently, the amount of capacity augmentation offered by the various options is not a useful discriminant if the criteria consider only the minimum capacity requirements. However, those options that provide capacity enhancement beyond the minimum requirement do provide insurance against delays in a replacement program.

CAPACITY AUGMENTATION	2		3A	3B	4A	4B
	SPEED UP	A-D	IOCE	DARC	HOST	HOST
1988 TRAFFIC	YES	YES	YES	YES	YES	YES
7 FUNCTIONS	YES	YES	YES	YES	YES	YES
RELIABILITY/AVAILABILITY CHARACTERISTICS	NEUTRAL	NEUTRAL	MINIMAL IMPROVEMENT	SMALL IMPROVEMENT	MED IMPROVEMENT	MED IMPROVEMENT
MAINTAINABILITY/HARDWARE	FAIR	FAIR	FAIR-GOOD	GOOD	EXCELLENT	EXCELLENT
COST	24M	32/64M	124M	45M*	252M	226M
SCHEDULE (FIRST SYSTEM OPERATIONAL)	84	85	85	86	86	85
RISK - TECHNICAL	HIGH LOW**	LOW	MED	MED	MED	LOW-MED
EASE OF TRANSITION	LOW	LOW	LOW	MED	MED	MED
COMPATIBILITY WITH LONG RANGE	THROW AWAY	THROW AWAY	THROW AWAY	THROW AWAY	PROBABLY USABLE HARDWARE***	PROBABLY USABLE HARDWARE***

* ASSUMING PRIOR IMPLEMENTATION OF ENHANCED DARC AND APPROPRIATE 9020 SOFTWARE CHANGES
** 12 MONTHS TO $330K FEASIBILITY STUDY WILL REDUCE RISK TO LOW ELSE ELIMINATE OPTION
*** MAY REQUIRE SUBSEQUENT UPGRADING/REPLACEMENT TO SUPPORT AERA

Table IV-2. Evaluation of Short-Term Options

IV.5.2 Reliability/Availability Characteristics

Options (4a and 4b) that replace the 9020 hardware but retain the software offer the most significant, potential, near-term improvements for the full system functions. These improvements are realized by replacing the 9020 and display channel hardware with state-of-the-art equipment. The amount of improvement is somewhat dependent on whether the 9020 peripherals are replaced (4a) or retained (4b).

Both the IOCE Replacement (3a) and Prime Channel DARC (3b) options offer slight improvements in full system functional reliability/availability by replacing elements of the 9020/display channel hardware with more modern hardware. In the case of Prime Channel DARC there is also the potential for improved failure mode performance in the en route computer system by virtue of the distributed processing architecture of the DARC system. This architecture offers the promise of being able to contain failures at the sector level, so that single point failures that affect the entire ARTCC become highly improbable. It should be noted, however, that Prime Channel DARC does eliminate the independent RDP backup channel and there may be some initial reliability problems to overcome with the new software (RDP/FDP split) configuration.

Options that retain the basic 9020 hardware and software, with modification for capacity enhancement only, offer essentially no improvement in reliability/availability characteristics of the en route computer complex.

IV.5.3 Cost

In terms of potential cost/benefit tradeoff, the 9020 memory replacement and processor/memory modification for faster operation is a very attractive option for simply overcoming a near-term capacity problem. This has to be weighed against the assessment that it is in fact the highest risk option in the areas of feasibility, reliability, and maintainability.

Prime Channel DARC and straight replacement of 9020As with 9020Ds are the mid-range near-term options in terms of cost. There is also a variation on straight replacement of 9020As by 9020Ds which calls for use of current technology solid state memory rather than core memory. The solid state memory variation is estimated to be less than half the cost of the straight core memory replacement.

Prime Channel DARC offers certain potential failure mode and maintainability advantages over the 9020D-for-9020A exchange. However, the development and transition risks are considered to be proportionately greater. It should be noted also that Prime Channel DARC cost estimates are predicated on FAA proceeding with development and implementation of the enhanced DARC system as it is currently defined. That is, the Prime Channel DARC cost estimate is an incremental cost using enhanced DARC as a base rather than Basic DARC.

IOCE Replacement is approximately mid-range in terms of cost for the various near-term options. However, it appears to offer no significant advantages over the lower cost DARC option, with the possible exception of marginally less development risk.

The highest cost near-term options are those requiring replacement of the 9020 hardware with modern machines that will accommodate the 9020 software. The high cost of these options dictates that their application to satisfying the far-term requirements must be given more serious consideration than is necessary for the other near-term options. In that respect the host options would appear to constrain the architecture of the advanced system, may introduce delays in developing and implementing the advanced system functions, and may require augmentation or replacement of interim hardware for advanced automation.

IV.5.4 Schedule

The straight capacity enhancement options of (1) 9020 memory replacement with memory/processor speed-up and (2) exchanging 9020As for 9020Ds appear to be the fastest responses to the near-term capacity problem. They are low enough in cost to obviate any concern over treating them as "throw away" options in the context of an overall (near and far term) solution. The memory/processor modification has significantly higher technical risk until feasibility is demonstrated. The major consideration in the 9020D - for - 9020A exchange appears to be the availability of surplus IBM 360/65 elements. Of the two computer replacement options (Section IV.4), 4b provides capacity augmentation some 12-15 months in advance of 4a, though it is a less rigorous and probably less reliable host of the software.

The software off-load options are one to two years later than the capacity enhancement options. This makes them marginal solutions with respect to the predicted onset of capacity short-falls. However, Prime Channel DARC at best is close enough in cost (considering all benefits) to straight capacity enhancement to make it a plausible contingency if the onset of capacity short-falls can be forestalled in some fashion.

The 9020 computer replacement options are only slightly farther out in time than the software off-load options, making cost the major factor in discriminating these against the software off-load options.

IV.5.5 Risk

The 9020 memory replacement and processor/memory modification is currently the highest risk option. The memory replacement is relatively low risk. However, the complexity of the interaction of the new Read-Only-Storage (ROS) and internal registers with the rest of the 9020 system make it difficult to predict how much speedup of the 9020A is possible. A 6-12 month experiment is required to modify a processor appropriately and determine the feasibility of the modifications and thereby minimize the technical risk. By contrast, there is minimum technical risk in replacing 9020A's with 9020D's, though the cost is

significantly greater. Among other options, those involving functional splitting of the software (IOCE Replacement and Prime Channel DARC) represent a greater risk than the computer hardware replacement options.

IV.5.6 Ease of Transition

Option 2b (Replace 9020As with 9020Ds) represents the lowest transition risk of all near-term options. FAA has already accomplished this at the Jacksonville ARTCC. Option 2a (Speed-Up 9020A) is potentially comparable to 2b in level of transition risk (depending upon the success of the feasibility study), but must be assigned a somewhat higher risk assessment simply due to the introduction of the modified hardware into the 9020 configuration.

All other near term options represent another level of trans on risk above the Option 2 alternatives, due to the extent of the ch ges that would be made to the overall en route computer configuration hardware and software) at the ARTCC. Specific risk areas vary with t options, but overall the remaining options have comparable levels of ansition risk.

IV.5.7 Compatibility with Far Term Requirements

No attempt is made to justify the straight capacity enhancement options and software off-load options in terms of far term requirements. They are considered as "throw away" systems to be developed and implemented only as expedients to offset current system deficiencies that are expected to become critical before a replacement system could be implemented to accommodate all of the requirements that must be satisfied by the air traffic control computer system (see Chapter II).

The high cost of computer hardware replacement with a system that will accommodate the 9020 software does not warrant its consideration as a near term capacity solution unless it can be factored into far term plans for the ATC computer system. A shortcoming of basing the full replacement program on a modern mainframe is that the full range of technical alternatives that could be used in a future ATC system is constrained. It may well be that another system architecture provides a better far term solution to the ATC problem. Specifically, there is an issue with respect to the level of fault tolerance that can be achieved with the mainframe architecture and its large, all-purpose operating system. These factors are considered in more detail in Chapter V.

IV.6 Benefit Cost Results of Near Term Options

IV.6.1 Background

Shortly after the issuance of the Senate Subcommittee's report, FAA began the development of a benefit cost model for use in evaluating all of the FAA's Engineering and Development (E&D) programs. From the outset, it was envisioned that the benefit cost model under development

would also be of use in analyzing various options for dealing with the ultimate replacement of the current en route computer system as well as any short range options to en masse replacement.

Today, the model is fully implemented and has played a key role in the development of the answers to the questions and recommendations raised by the Subcommittee's inquiry.

IV.6.2 Methodology

The methodology used in the benefit cost model is straightforward. Input data is required in the form of time streams of costs and benefits. The model then aggregates the various costs and benefits for each option, discounts these aggregations, and then finally ranks the options according to their benefit to cost ratio and benefit minus cost difference.

IV.6.3 Guidelines

The studies were conducted under the following guidelines:

a) sunk costs and benefits were not included

b) costs and benefits were discounted at the OMB recommended rate of 10% per year compounded annually

c) costs and benefits were measured in terms of the 1981 dollar's purchasing power

d) no inheritance or scrap values were included

e) the time span covered 30 years from CY-1982 through CY-2011.

IV.6.4 Benefits

The discounted benefits shown in Table IV-3 represent reductions in cost to the users of the system as well as to the government.

The four benefit categories included were:

a) reductions in fuel costs
b) reductions in delay costs
c) reductions in the controller work force
d) reductions in the maintenance work force

TABLE IV.3

DISCOUNTED BENEFITS
(billions of dollars - 81)

OPTION	DELAY	FUEL	MAINT.	CONTROLLER	TOTAL BENEFITS
2A	1.20	2.13	0.0	0.71	4.04
2B	1.79	2.13	0.0	0.71	4.63
3A	1.02	2.13	0.0	0.71	3.86
3B	0.91	2.13	0.0	0.71	3.75
4A	1.80	2.13	0.04	0.71	4.68

A safety benefit was quantized separately in terms of reduced risk rather than in terms of monetary units. The translation of reduced risk into monetary gain is an almost impos-ible task from a statistical standpoint given the outstanding safety record of the ATC system to date.

It is still too early in the program's evolution to develop meaningful reliability cost and benefit profiles as that level of specificity has not been reached. Conseqeuntly, no monetary benefits or costs associated with safety and reliability were included in the analysis.

IV.6.5 Costs

The discounted costs shown in Table IV-4 include the development and implementation of a series of E&D programs all related to the performance of the en route function in the ATC system. These programs are therefore interrelated and definitely synergistic with respect to the en route function. Costs include the development as well as the implementation phases for each of these programs.

The program costs included are:

a) Hardware and/or software for the various computer options
b) Mode S Ground
c) Mode S Avionics
d) Other

    1) Conflict Alert for VFR Intruders
    2) Conflict Resolution Advisory System
    3) En Route Metering
    4) Electronic Tabular Display Capability in the Sector Suite Interface
    5) Mode S System Interface
    6) Central Weather System Interface
    7) Terminal Information Display System Interface

IV.6.6 Results Obtained

The discounted benefit to cost ratios and the discounted benefit minus cost differences of the five near term options described in Section IV-4 are shown in Table IV-5.

All of the near term options offer attractive benefit to cost ratios as well as significant benefit to cost differences. The discounted benefit/cost differences and the discounted benefit/cost ratios do not provide a significant enough discrimnant among the near term options because they are so similar. The choice among the near term options must therefore be based on other considerations.

TABLE IV-4

DISCOUNTED COSTS

(billions of dollars - 81)

OPTION	COMPUTER REPLACEMENT	MODE S GROUND	MODE S AVIONICS	OTHER*	TOTAL COSTS
2A	0.02	0.0	0.0	0.31	0.33
2B	0.06	0.0	0.0	0.31	0.37
3A	0.11	0.0	0.0	0.31	0.42
3B	0.04	0.0	0.0	0.31	0.35
4A	0.18	0.0	0.0	0.31	0.49

*Consists of Conflict Alert for IFR/VFR, Conflict Resolution Advisories, En Route Metering, Electronic Tabular Displays, Mode S Interface, Central Weather System Interface, and Terminal Information Display System.

TABLE IV-5

DISCOUNTED SUMMARY
(billions of dollars - 1981)

OPTION	TOTAL BENEFIT	TOTAL COST	B/C RATIO	B-C
2A	4.04	0.33	12.2	3.71
2B	4.62	0.36	12.8	4.26
3A	3.86	0.41	9.4	3.45
3B	3.75	0.34	11.0	3.41
4A	4.67	0.49	9.5	4.18

V. FAR TERM OPTIONS

V.1 Introduction

The far term options address alternative approaches to full replacement of the existing en route ATC computers and the introduction of advanced automation functions into the ATC system. For all far term options considered in this analysis it has been assumed that the computers would be replaced before the sector suites.*

The far term options fall into two major categories: those in which an interim computer system which will accommodate the 9020 software (option 4) is used to solve the near-term problem and those in which one of the other near term options is chosen (Section IV.4). In the first category, the interim system has a significant impact on the replacement approach - either by deferring a full replacement or by becoming an integral part of the replacement system. In the latter category the near term capacity solution is considered a "throw-away" and therefore places no constraint on the full replacement option. The analysis of the latter options does not include cost or impact of the particular near term system that might be used to provide interim capacity.

The numbering of the far term options begins with number 5, continuing on from the numbering of the near term options. The numbers were assigned in the order that the options were defined. For clarity of presentation, the options are discussed out of numerical order. (The options were not renumbered, so as to remain consistent with earlier documents and presentations.)

In all the discussion that follows, "Interim System" refers to new computer hardware executing the existing software, as earlier defined for Options 4a and 4b. "Replacement System" means both new hardware and software, but without the advanced automation functions 8 through 11. "Advanced Computer System" refers to the ultimate configuration of new hardware and software that provides all the advanced automation functions.

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*Subsequent to this effort, the PATCO strike by the FAA's air traffic controllers has caused FAA to reconsider its priorities in ATC automation. The potential productivity gains associated with a new radar display and associated computer data entry and output features are now more attractive in the near term than they were prior to the controller strike. FAA is consequently re-evaluating the option of display replacement before computer replacement.

If an Interim computer is chosen as the solution to the near term problem, then a fundamental next question is, should the Interim computer be kept as part of the far term system or should it be a throwaway? Options 5 and 8 examine these alternatives.

Option 5, Interim Host Followed by Full Replacement System. This option is responsive to the suggestion of the Senate Investigations Staff Report [34] that the FAA consider an interim system to solve its capacity problems and defer a full replacement until a better definition of computer requirements is in hand. Because it is assumed for this Option that the interim system will be a throwaway, Option 4b is chosen as the near term solution in order to minimize the cost of the interim. Full requirements for advanced automation (functional improvements 8-11), permit development of the ACS in a single step, in effect skipping the replacement system step.

Option 8, Replacement System Built Around Interim Host. In this Option, the interim system executing existing software becomes the first building block for the replacement system and eventually the ACS. Depending on the urgency of the near term capacity enhancement requirement, either Option 4a or 4b could be selected as the interim for this option. Because the interim system in this option will also be kept for the far term, it is appropriate to buy all new peripherals with the interim. Thus, for analysis purposes Option 4a is chosen as the near term solution for this option. A Replacement System development effort is started at the same time as the interim rehosting effort. After a full concept/design phase, the replacement software is designed and written to provide a suitable far term base. Finally, the hardware and software are both enhanced to create the Advanced Computer System. Two sub-options consider alternate means of moving from Replacement to Advanced Computer System:

Option 8a, Distributed Approach. It is assumed that the Replacement System hardware will be kept, and that the needed hardware enhancements for the Advanced Computer System will be gained by adding additional processors outboard of the mainframe computer.

Option 8b, Mainframe Approach. In this sub-option, the hardware enhancement for the Advanced Computer System will be achieved by substituting a larger system (perhaps bus oriented) of the same family (presumably incorporating the latest technology) for the Replacement System hardware.

Options 6 and 7 consider the cases in which the computer replacement program is not affected by the solution selected for near term capacity problems. Because the near term solution is not considered in the analysis of these two options the cost comparisons between the far term Options must take into account the fact that only options 5 and 8 include the cost of a near term solution.

Option 6, Multi-Step Transition to Replacement System. Responding to recommendations from several quarters, this Option considers replacing the 9020 in two steps. The first step would replace the Radar Data Processing and Display portions of the existing hardware and software; the second step would replace the remainder of the system. The aim of a multi-step approach is to replace the 9020 in smaller, more manageable steps. Deferring acquisitions as long as possible permits the buyer to take best advantage of rapidly-moving technology. After the two-step Replacement, a third step would upgrade to the Advanced Computer System.

Option 7, Single-Step Transition to Replacement System. In this Option, the Replacement System would be obtained in one step. The Replacement System would subsequently be upgraded to the Advanced Computer System.

Option 7 is the approach that has formed the basis of FAA's replacement program planning. It has been presented to Congress [35] and at a special meeting on December 2, 1980 to industry at large [36]. Based on discussions with the Office of Federal Procurement Policy, regarding OMB Circular A 109, three alternative acquisition strategies were analyzed in detail for Option 7. The conclusions of this acquisition strategy analysis applies to all far term options, although in cases where hardware is to be procurred early, the duration of competition needs to be limited since hardware can not be ordered until all but one contractor have been eliminated.

V.2 Evaluation Criteria for the Far-Term Options

This section describes the major considerations that will guide the evaluation of potential solutions to the far term ATC computer requirements. As one might expect, there are some similarities and some differences with respect to the criteria defined for the evaluation of the near term options. It should be noted that the far term options are evaluated in terms of total program aspects and potential for meeting overall system requirements, where the near term option evaluation was based more on the relative technical merits of specific design proposals. The evaluation areas for the far term options are:

- Schedule
- Cost
- Risk
- Impact on FAA Resources
- Ability to Evolve
- Transition Impact

Cost, risk, and transition criteria are applied in the same manner for both near and far term option evaluations. Other consideratio[illegible] are distinctly different for the far term options.

To achieve the benefits described in Section II (Requirements), it is highly desirable that FAA put in place as soon as possible the advanced ATC automation functions that are currently in the FAA far term development stages. In that context the advanced functions are expected to be defined in some detail within a time period that is generally consistent with the estimates for developing and implementing the required computer resource. Consequently, schedule estimates associated with various approaches to implementing the far term functions are a potential discriminant in the evaluation of the options.

FAA technical and program management resources available for a program of this magnitude are limited. Therefore, evaluation of the far term options considers the impact of a particular strategy for developing and implementing the new system on FAA resources.

The far term options must be defined to account for all of the far term requirements. As a practical matter it is anticipated that there may be features implicit in the various options that cause some options to be more attractive than others in terms of allowing unconstrained evolution to a system that satisfies all requirements. Also, there are differences in the evolutionary characteristics of the options to the extent that some options provide certain benefits early at the expense of satisfying all requirements later. Consequently, this was identified as a specific evaluation area for the analysis of far term options.

V.3 Assumptions and Groundrules

A number of assumptions and groundrules were established as a basis for the definition and analysis of far term options. These include: scope of replacement; general assumptions regarding the current system; acquisition groundrules; schedule groundrules; and cost assumptions. These common assumptions and groundrules were laid out to obtain a valid comparison of the various far term options. The schedules and costs developed for the far term option analysis form the starting point for program planning of the Advanced Automation Program. It is expected that both costs and schedules will be refined to reflect the priorities, option definition, and acquisition strategy ultimately selected by the FAA Administrator.

The scope of the program addressed by the far term options is:

- Replacement of 9020 central computer complex, peripherals, and interface hardware;
- Replacement of display channels (CDC or 9020E) and existing sector suites;
- Replacement of the DARC backup channel;

- Replacement of application and support software by new software based on a total system design (includes sector suite).

- System design that will allow evolution to the ACS without significant redesign and recode of the initial replacement software.

In defining the far term options, the following general assumptions were made:

- a solution to near term capacity problems is possible without dependence on the far term option;

- the future sector suite, to be implemented after the computer system, is required before the ACS can become operational;

- the sector suite, while included in the design, schedule, and cost, was not subjected to technical analysis because it does not represent a technical discriminant among the options;

- the future sector suite will have the capability to support the electronic tabular display functions in the sector suite;

- FAA will be able to maintain the current computer hardware until the system can be replaced under any given option;

- A transition period is provided at each replacement step that permits parallel operation of the existing system with the newly deployed system;

- far term options, by definition, must meet all system requirements.

The assumptions/groundrules on schedule and acquisition are:

- In keeping with the A-109 acquisition philosophy all options contained a front-end paid competitive concept/design phase in which all contractors develop a design for the total system. Multiple contracts are denoted by multiple lines in the schedule diagrams;

- The particular acquisition strategy (duration of phases and number of contractors funded in each phase) and schedule for any given option were selected to provide a comparison of the options, but were modified to make common sense (for example, the competitive phase of option 8 was quite short because host computers, which are needed early for capacity reasons, cannot be ordered until all but one contractor has been eliminated);

- To reduce the length of the total program, it was assumed that all contractors would continue work during the evaluation period at the end of each competitive phase;

It was assumed, for schedule purposes, that the program would not be split into separate contracts for different parts of the development (option 5 is an exception);

- Option 7 was selected as the vehicle to compare various A-109 approaches, i.e., variations in multiple contracting. For all other options, only one acquisition strategy was considered, i.e., a single multiple contracting approach.

- Software development schedules determined to be the critical path for all options, were estimated using the RCA PRICE-S model and FAA estimates of the various application and support software modules (these estimates compared favorably with the widely used SLIM model).

The following cost assumptions were made:

1. The costs for the far term options include cost estimates for the cost categories of Management; Research, Development, Test, and Evaluation (RDT&E); and Investment. These categories consist of the same cost elements as presented in Chapter IV;

2. Operational and maintenance (O&M) costs are not included in the cost estimates presented. O&M cost estimates are presented in detail in reference 9;

3. Software development costs were estimated using the RCA PRICE S model. This model emulates the processes by which experienced managers and software developers assess the cost and schedule for software projects;

4. Hardware development and acquisition costs are based upon the architecture assumed for each far term option. dual mainframe computer systems are considered for the Interim System of option 5, the Interim and Replacement Systems of 8a, and all systems of 8b. Distributed architectures based on off-the shelf components are considered for the Replacement and Advanced Computer Systems of option 5, 6, and 7 and the Advanced Computer System of option 8a;

5. The option cost estimates include the cost of multiple contractors during the phase called for by the particular far term option;

6. For all far term options, it is assumed that the systems will go to 26 sites;

7. The total option cost estimate includes 1000 sector suites for the en route centers (23) plus the three support facilities;

8. Hardware acquisition costs have been reduced to anticipate probable reductions in cost due to technology advances. Approximately 90% of dual mainframe systems and 80% of distributed systems are subject to cost reductions (based on percent of cost attributed to processors and memory). The period for cost reductions extends from January 1, 1982 to the end of the appropriate design phase. Technology advances are assumed to decrease hardware costs by 7% per year, assuming no inflation.

V.4 Definition of Options

V.4.1 Interim Systems Using Computers Capable of Executing Existing Software

A replacement strategy that begins with a rehosting of NAS software on a mainframe executing the existing software is attractive because it combines capacity relief with replacement of the aged 9020 hardware. On the other hand, there is a risk that the interim, computer replacement will impose an architecture that will make it difficult to satisfy the requirements of the far term system. Further, a host system becomes available later than some other viable near term capacity solutions but still early enough to provide a comfortable schedule before the projected onset of delay days with the 9020 system.

V.4.1.1 Interim Host Followed by Full Replacement System (Option 5)

This option is a two-step evolution of the current computer system to ACS. The first step entails replacement of the current hardware with new state-of-the-art computers capable of executing existing software as discussed in Option 4b. The system resulting from this first step is the interim system. The second, which replaces this interim system, represents a deferred initiation of the replacement program. Therefore it is possible to build ACS in a single step after a longer advanced automation definition period than the other options.

Figure V-1 illustrates both steps of this option. The bold blocks at the end of each step, as before, denote changes to the computer system, i.e., a new mainframe computer at the end of the first step and a completely new system with new hardware and software at the end of the second step. Such a full replacement includes the implementation of new computer hardware and the design and coding of new software to replace the existing NAS software. The second step also entails the development of new software for all eleven functional improvements. The new functions would be activated as appropriate. Displays would be replaced after the interim system is in place, but before implementation of the new computer system with advanced automation capabilities. This option provides an early relief of the capacity problem, and some reduction in outages due to the use of new-technology hardware.

Technical and Transition Feasibility. Of the three interim approaches, this option places the fewest contraints on the evolution to ACS because the interim system is treated as a throw-away. Near-term capacity problems are alleviated by the interim hardware. Deferral of implementation of the far term system will allow time for a better understanding of the advanced automation system, and thus a better design. Further, the software for the eleven functional improvements could be developed in a single step. The transition impact of Option 5 is low, because of the small number of steps involved.

Cost and Schedule. Option 5 is estimated to cost $1.50 billion. The detailed schedule for this option is indicated in Figure V-2. The first interim system would be available early in 1985; all centers would be equipped by the end of 1987. Design of the ACS would

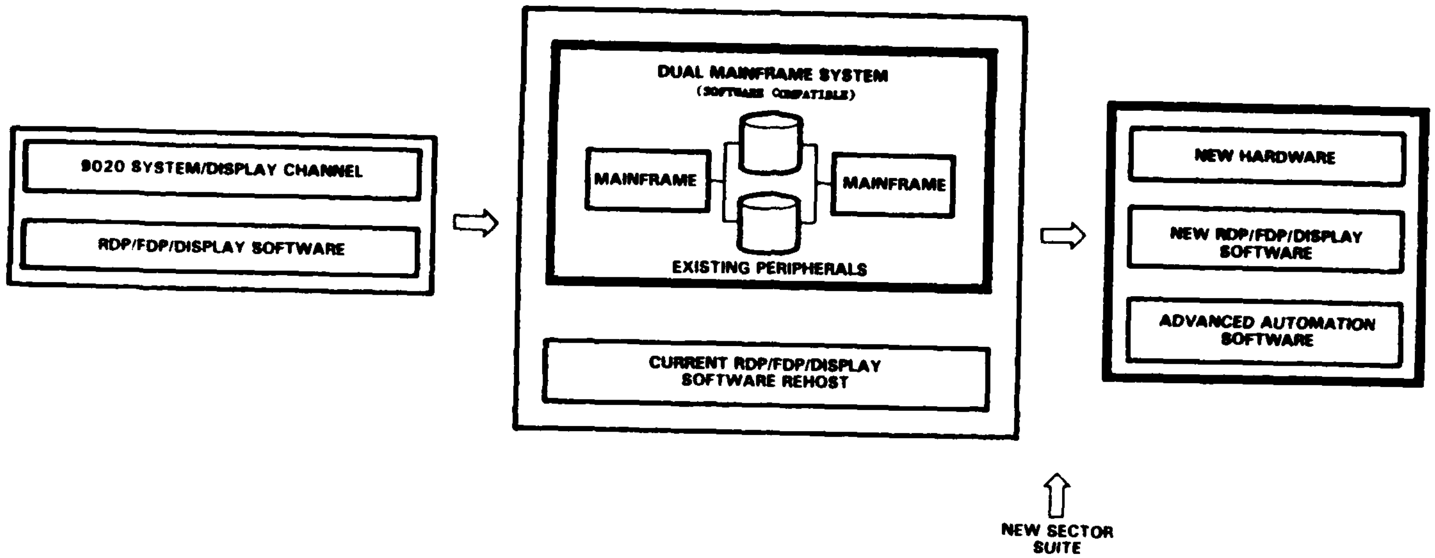
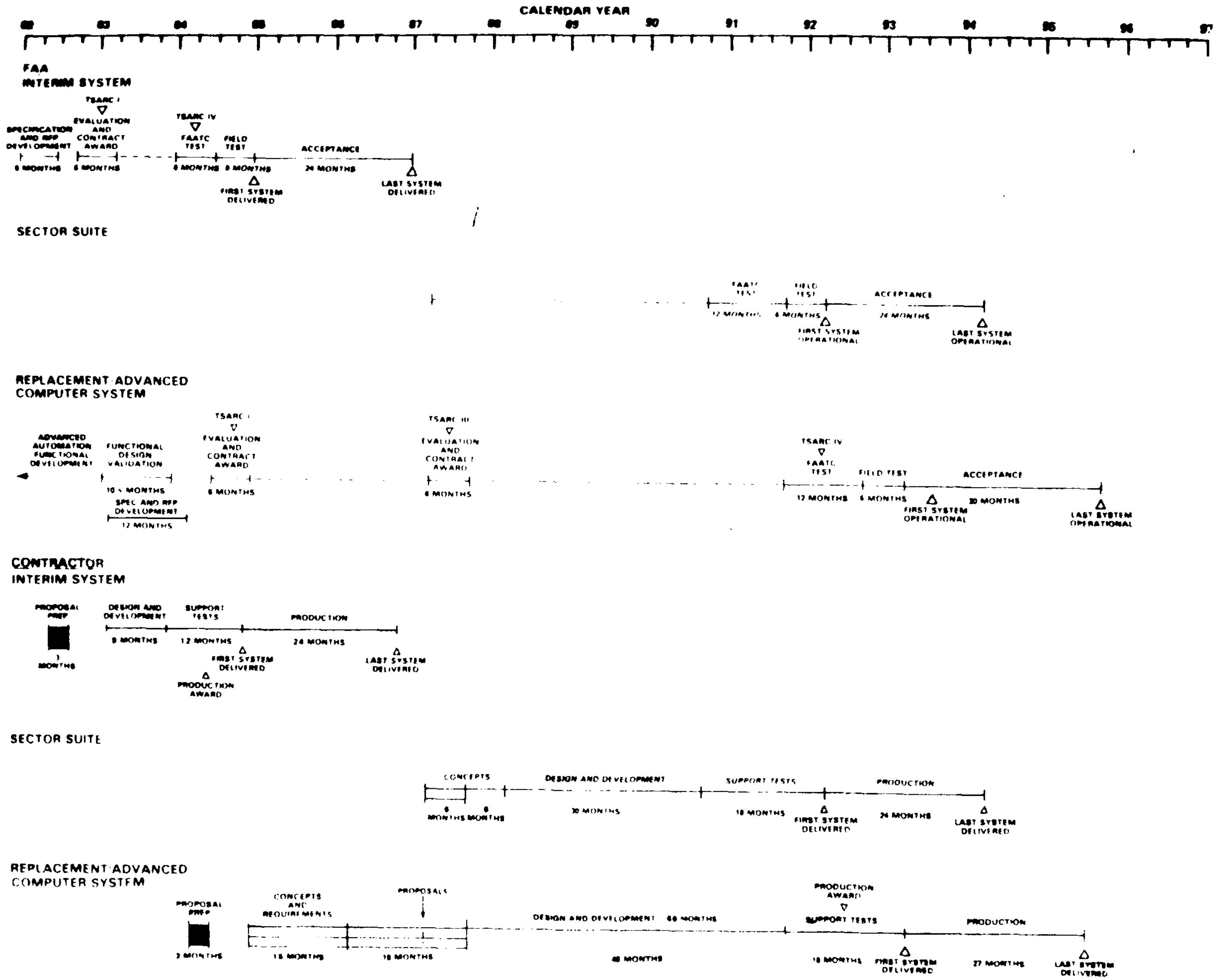


Figure V-1. Option 5, Interim Host followed by Full Replacement System


CALENDAR YEAR
FAA
INTERIM SYSTEM
SPECIFICATION AND RFP DEVELOPMENT
TSARC I
EVALUATION AND CONTRACT AWARD
TSARC IV
FAATC TEST
FIELD TEST
ACCEPTANCE
24 MONTHS
FIRST SYSTEM DELIVERED
LAST SYSTEM DELIVERED
SECTOR SUITE
FIRST SYSTEM OPERATIONAL
LAST SYSTEM OPERATIONAL
REPLACEMENT ADVANCED COMPUTER SYSTEM
ADVANCED AUTOMATION FUNCTIONAL DEVELOPMENT
FUNCTIONAL DESIGN VALIDATION
SPEC AND RFP DEVELOPMENT
12 MONTHS
TSARC III
12 MONTHS
30 MONTHS
CONTRACTOR
INTERIM SYSTEM
PROPOSAL PREP
3 MONTHS
DESIGN AND DEVELOPMENT
SUPPORT TESTS
PRODUCTION
12 MONTHS
24 MONTHS
PRODUCTION AWARD
SECTOR SUITE
CONCEPTS
DESIGN AND DEVELOPMENT
30 MONTHS
SUPPORT TESTS
18 MONTHS
REPLACEMENT ADVANCED COMPUTER SYSTEM
PROPOSAL PREP
2 MONTHS
CONCEPTS AND REQUIREMENTS
PROPOSALS
18 MONTHS
48 MONTHS
27 MONTHS

commence in 1987, with the first new computer system operational by 1993. The advanced automation functions will have to be introduced gradually over a one to two year period after that. This leads to the latest introduction of highly automated ATC.

V.4.1.2 Replacement System Built Around Interim Host (Augmentation Approach) (Option 8a)

This is a three-step replacement of the current computer system. The first step provides an Interim System by replacing the current system with state-of-the-art computers capable of executing the existing software (including new peripherals) and rehosting the current software on those computers. This interim system selected for the analysis of this option is the one proposed under Option 4a. In the second step the rehosted software would be replaced by new software (with the first seven functional improvements); no hardware changes are made in this step. Finally, the mainframe computers would be augmented with additional hardware (computers and interface equipment) and advanced automation software would be developed to achieve an Advanced Computer System. (See Figure V-3). Thus, there will be some early reduction in outages because of the presence of new hardware, and new software would be available three years earlier than under the previous option.

Technical and Transition Feasibility. The transition impact of this option is somewhat higher than Option 5 because of the extra, software development step. The system's evolution is more restricted since hardware is retained across the transition steps, but it does permit the design of the system around a host to meet the far term requirements. The risks associated with the interim system remain. There are the questions of meeting the reliability requirements with the augmented system, the overhead imposed by the large operating system required by the software rehost, and the constraints on selection of an optimal system architecture for the ATC system of the 1990's. If a single contractor provides both the host computer and the replacement software as assumed for this study, the competition period is very short because the winning contractor must be selected early as the host computers can be installed at the centers.

Cost and Schedule. The total cost of this option is estimated to be $1.39 billion; the replacement system is estimated at $921 million, with the ACS incremental cost $470 million. The replacement system would be in place by 1989, with full ACS available in 1992. A detailed schedule for Option 8 is presented in Figure V-4.

V.4.1.3 Replacement System Built Around Interim Host (Replacement Approach) (Option 8b)

Like the previous option, this approach is a three-step replacement of the 9020 system. The first two steps are the same as described above: rehosting the current software on a new hardware configuration (the interim system), and then rewriting the software. The final step, however, would be to replace the interim hardware with a completely new and more powerful system that could and probably would be a bus architecture. This system would be sized to run the advanced automation software. Figure V-5. is a graphical representation of these steps.

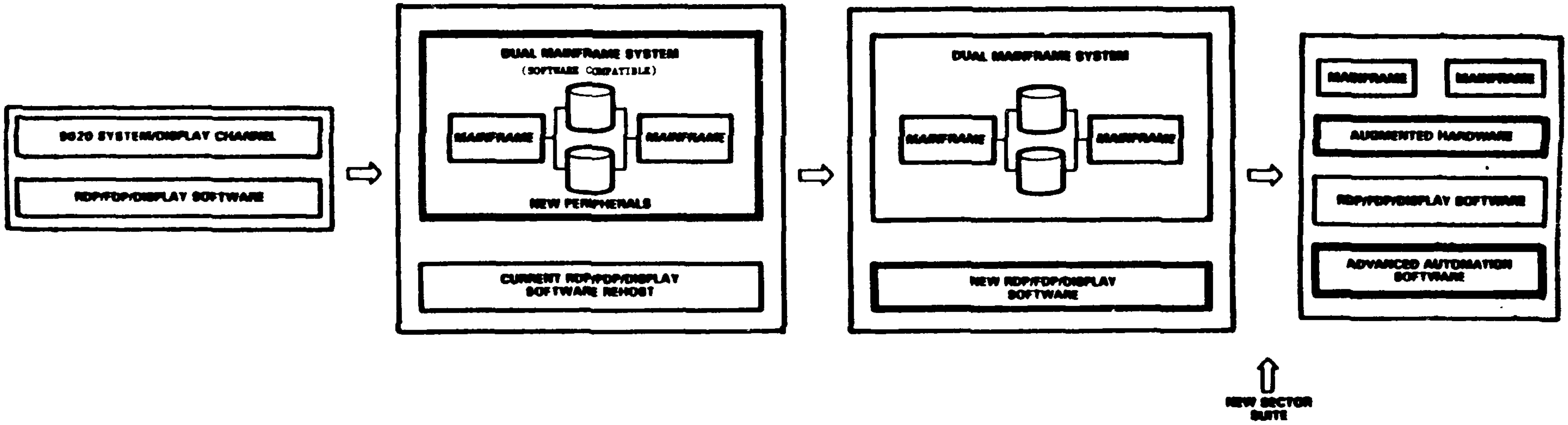


Figure [illegible]. Option 8a, Replacement System built around Interim Host, Distributed Approach

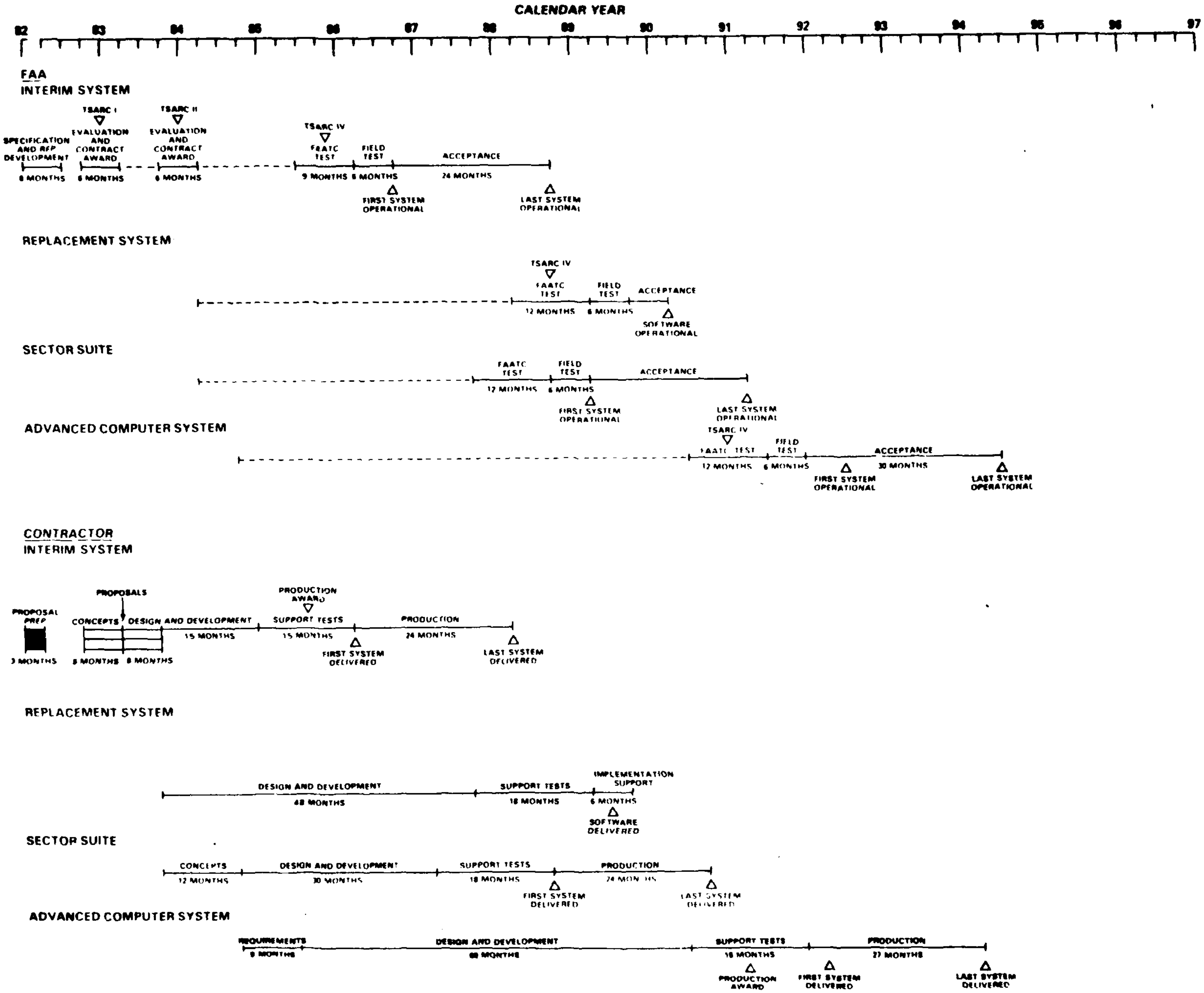


Figure V-4. Schedule for Option 8, Replacement System built around Interim

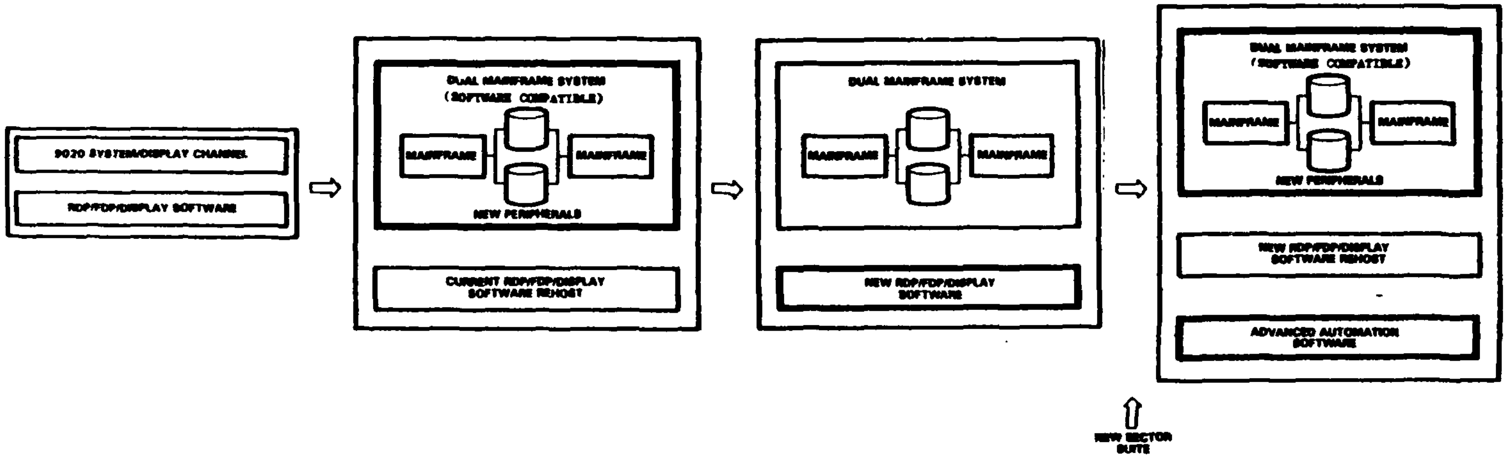


Figure V-5. Option 8b, Replacement System built around Interim Host, Mainframe Approach

Technical and Transition Feasibility. This option is very similar to Option 8a. The transition from the replacement to the ACS is eased somewhat by the fact that the interim system hardware is replaced in total. However, there are significantly greater architectural constraints, and the risk of meeting the reliability requirements of the highly automated system in ACS.

Cost and Schedule. The cost of this option is estimated at $1.45 billion; the replacement will cost $912 million and the ACS increment is $541 million. Schedule information for Option 8 is shown in Figure V-4.

V.4.2 Direct Replacement of the 9020

Unlike the previous options, the approaches examined in this section do not involve an interim system. The 9020 hardware and software is replaced directly, either in a stepwise manner (Option 6), or in a single step (Option 7). Since no interim system is implemented, capacity relief for the near term under these replacement approaches requires additional action (possibly one of the near term options discussed in Chapter IV) which is neither treated nor costed in the discussions which follow.

V.4.2.1 Multi-Step Transition to Replacement System (Option 6)

This option is a multi-step evolution of the current computer system. The first step augments the current computer system with new hardware and implements new software for RDP-related functions and display functions (RDP Development step; this step is like Prime Channel DARC except that it is done as a part of the overall design instead of enhancing the available system). The first step is shown in Figure V-6 as a bold block containing new hardware and new RDP/display software. This step includes a top level design of the full ACS. Certain of the functional improvements described in Chapter II (1, 2, 3, 5, and 6) are included in this step. The second step augments this system with additional new computers and replaces the remaining existing software, adding the balance of the functional improvements (FDP Development step). This second step is shown in Figure V-6 as a bold block containing new hardware and new FDP software. The final step of this option involves the augmentation of the system with additional new computers and the development of new software associated with functional improvements 8 through 11 (the ACS); it is illustrated as the rightmost bold block in Figure V-6.

Technical and Transition Feasibility. In the case of this option a technical risk trade-off is involved. The replacement system is developed and implemented incrementally in an attempt to minimize risk involved in the individual steps. This is accomplished at the possible expense of a longer overall completion time for the full replacement. It may require that elements of the 9020 to remain in service for a longer period of time than would be required by other options. As noted earlier, the 9020 software functional split required in the first step poses a schedule risk in this option. The need to make a portion of the replacement computer system work hand-in-hand with 9020 FDP poses a constraint on the design of the new system.

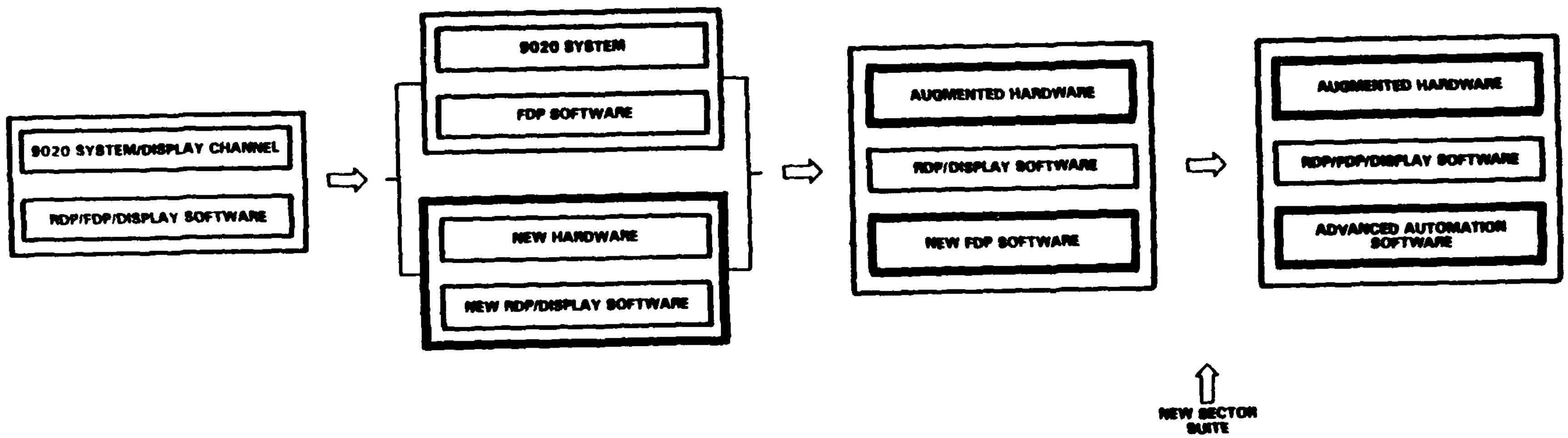


Figure V-6. Option 6, Multi-Step Transition to Replacement System

Cost and Schedule. Option 6 is estimated to cost $1.38 billion total; the replacement system will cost $1002 million and ACS will add an increment of $380 million. The replacement RDP system would be available in 1989, with FDP operational in 1991 and full ACS implemented at all sites by 1995. The Option 6 schedule is summarized in Figure V-7.

V.4.2.2 Single Step Transition to Replacement System (Option 7)

This is a two-phase program to upgrade the current computer system. The Replacement System phase replaces in a single step the current computer system with new hardware and implements new software, replacing the existing NAS software and adding functional improvements 1 through 7. This phase includes an initial top level design of the full replacement system and ACS. Figure V-8 presents the result of this step as a bold block containing new hardware and new FDP/RDP display software. The Advanced Computer System phase augments the computer system with additional new hardware and software for functional improvements 8 through 11. The ultimate system for this option is the functional equivalent of the final systems for Options 5, 6, 8a and 8b with possible architectural differences.

Technical and Transition Feasibility. Conceptually, the direct replacement approach presents the simplest transition scenario: a single switchover is made between the old hardware and software to the new system. Some problems, such as the availability of space for the colocation of the old and new hardware, need to be examined in detail. Technically, this option is desirable since the hardware and software are designed together; technical risk associated with choosing an architecture which might constrain the system's functional evolution is minimized under this approach.

Acquisition Approaches. Three possible acquisition strategies were considered under this option for an A-109 compatible procurement of the Advanced Computer System. They are designated according to the number of contractors competing at each development stage: concept development, detailed design and subsystem demonstration, prototype development and production. The strategy for the acquisition plan in all cases is to minimize the schedule while maintaining a cost limit. All result in full implementation of ACS by 1995. The cost ranges from approximately $1.33 billion to $1.52 billion, including design, hardware, software, and displays. Each strategy is discussed in detail below.

5-3-2-1 (Suboption 7a)

This strategy envisions award of concept development contracts to a large number (three to six) of offerors. The three best concepts would be chosen for detailed design and subsystem demonstration, and the two best design contractors would then be selected to proceed to

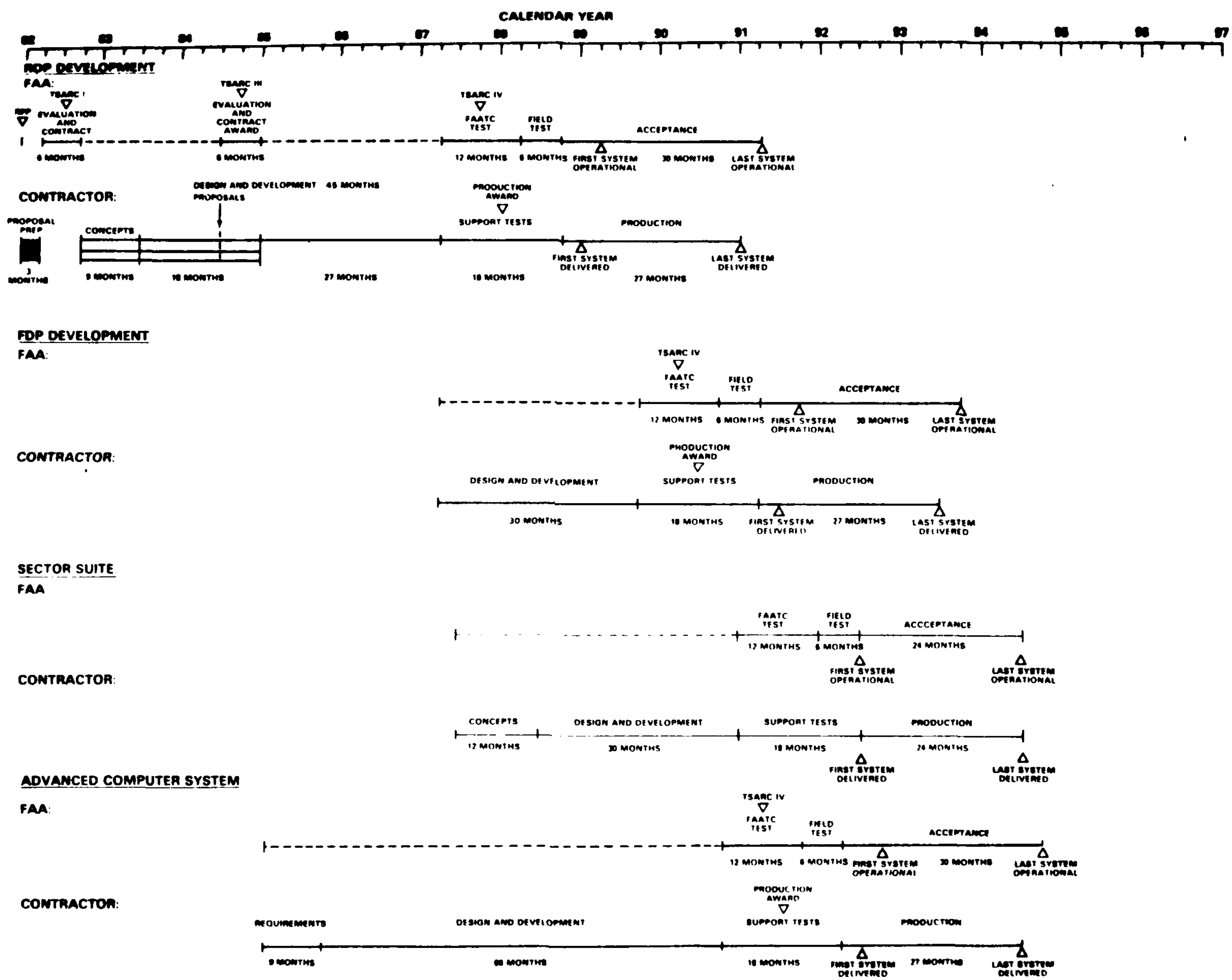


Figure [illegible] Schedule for Option [illegible], Multi-Step Transition to Replacement System

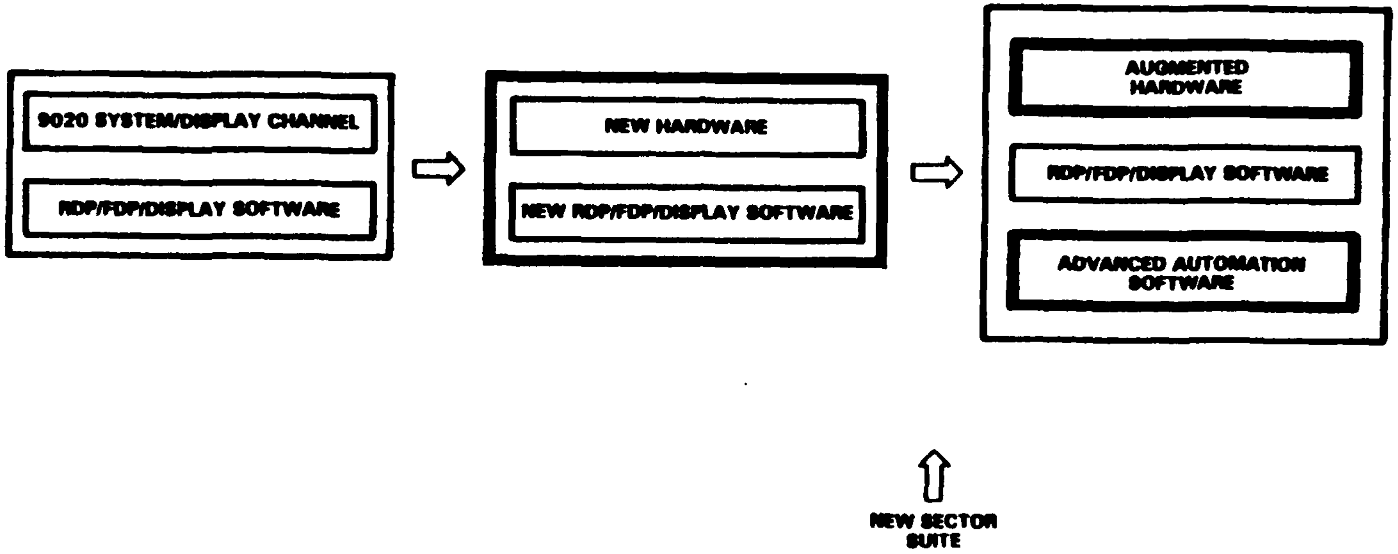


Figure V-8. Option 7, Single Step Transition to Replacement System

the prototype phase. A comparative test and evaluation program would then result in selection of one of the contractors for production and implementation of the Advanced Computer System. The first replacement system would be available in 1990; the first ACS would be implemented by 1992, with ACS operational at all centers by 1995 (Figure V-9). This suboption is estimated to cost $1.52 billion, with the replacement cost $1082 million and the ACS component $439 million.

The 5-3-2-1 strategy minimizes technical risk by keeping competition throughout the development cycle. It permits an expedited initial award because a relatively large number of concept development contracts is envisioned; it is expected that, due to the size and scope of the procurement, only a few (less than eight) proposals would be received, and that all acceptable proposals could be awarded contracts. It is the most costly strategy in terms of both acquisition outlays and government personnel required due primarily to the dual prototypes. The dual prototype phase also adds to the schedule because production "go ahead" cannot be given until after full test and evaluation is completed, results are reviewed and source selection is completed; the schedule for replacement is thus about one year later than under the other options.

<u>3-1-1-1</u> (Suboption 7b)

In this strategy a smaller number of contractors is chosen for award of concept/design contracts. These designs are evaluated and one is chosen to complete the detailed design, prototype and production of the Advanced Computer System. Because of the reduced competition, risk (both technical and schedule) is greatest in this strategy. To minimize this risk, the concept/design phase is planned to last longer in this strategy than in either the 5-3-2-1 or 5-2-1-1. This allows for more products to be delivered and the design to be carried one step closer to detailed design in order that the best contractor is selected to proceed. Because of this longer initial phase, the overall procurement cost differential between the 5-2-1-1 and 3-1-1-1 strategies is not significant. The replacement system would cost $966 million, and ACS would add $365 million, for a total Option 7b cost of $1.33 billion. Because the initial award is to a smaller number of contractors, proposal evaluation is much more critical and time consuming. This strategy does minimize government resources required. The first replacement system would be available in 1989; the first ACS would be operational early in 1992 (Figure V-10).

<u>5-2-1-1</u> (Suboption 7c)

This strategy is basically similar to 5-3-2-1 except that only two contractors are selected for the detailed design and subsystem demonstration phase. Then one of these is chosen for prototype development and, if successful, production and implementation of the Advanced Computer System.

Technical risk is somewhat higher here because competition is not kept into the production phase, but a competitive subsystem demonstration would give confidence that the objectives can be met. Costs in terms of both contract outlays and government personnel are considerably

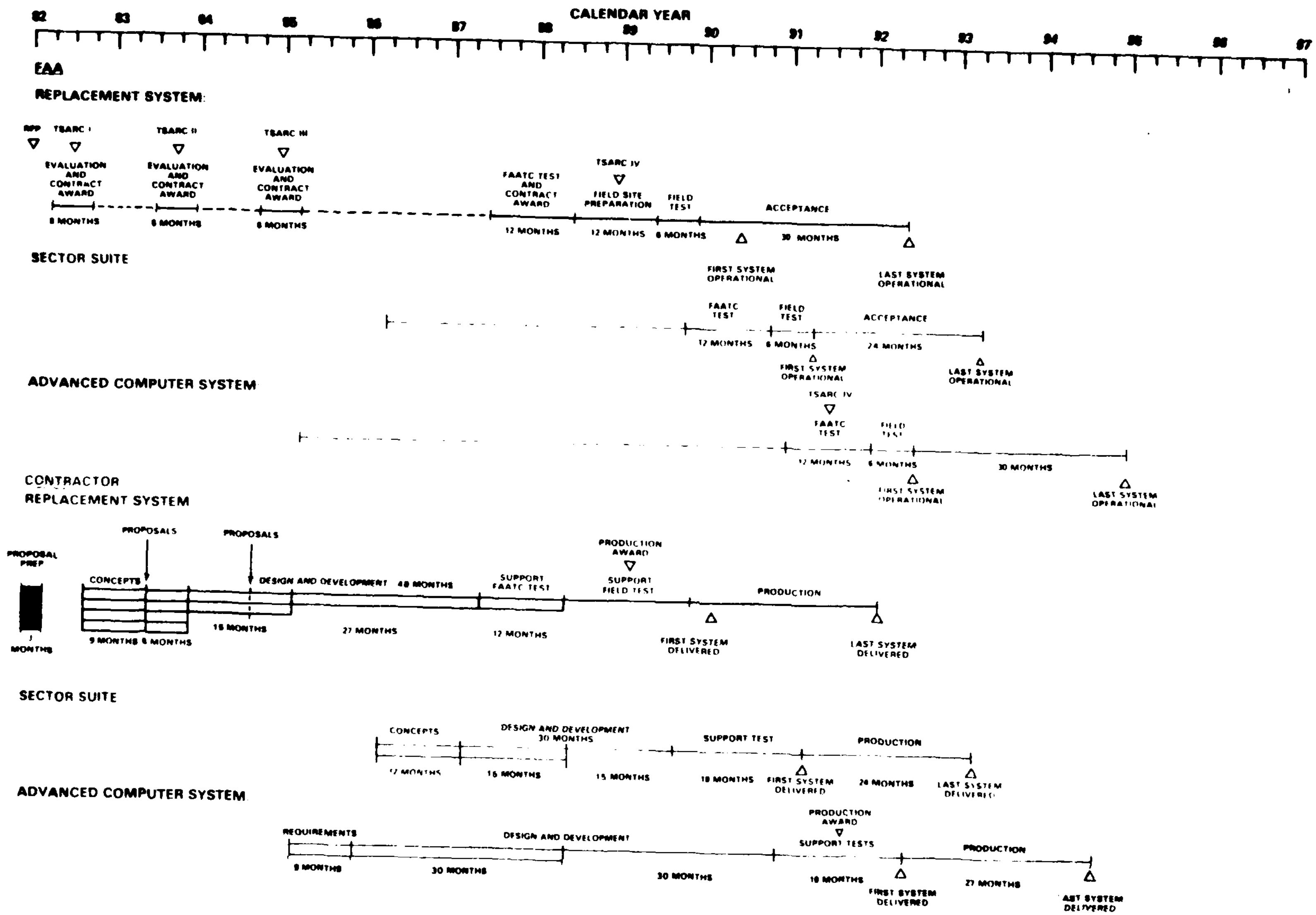


Figure V-9. Schedule for Option 7a, Single Step Transition to Replacement System (5-3-2-1)

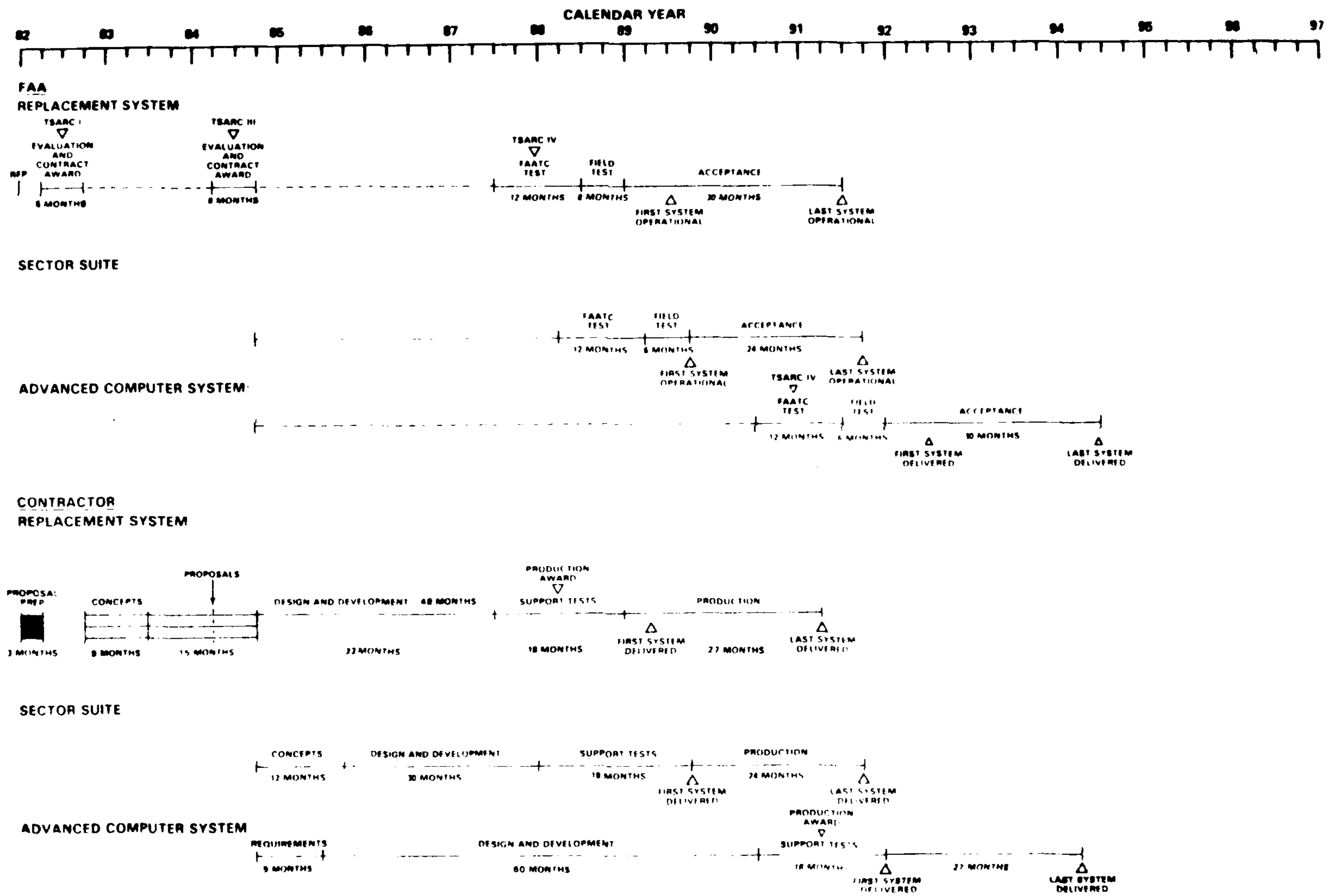


Figure V-10. Schedule for Option 7b, Single Step Transition to Replacement System (3-1-1)

reduced over the 5-3-2-1 strategy Under Option 7c the total program cost is estimated at $1.39 billion; replacement is estimated at $1009 million and the ACS increment at $376 million. The number of contracts awarded for the detailed design and subsystem demonstration phase is not critical, but 2 is the ideal number in terms of competition, project management, evaluation, and overall procurement cost. The first replacement system would be available in 1989; ACS would become operational early in 1992 (Figure V-11).

The 5-2-1-1 strategy is recommended as the best strategy for option 7. It allows an expedited initial award of contracts, keeps competition until prototype award and permits a reasonable and achievable government resources expenditure while also permitting a nearly optimum staffing and funding profile for the contractors. The longer schedule and higher resource requirements and costs of the 5-3-2-1 strategy are not judged to be worth the reduced technical risk. The high risk of the 3-1-1-1 strategy is judged to more than offset its advantages.

V.5 Analysis of the Far Term Options

In this subsection the evaluation criteria previously discussed are applied to the far term options defined in the preceding subsection. The intent is to provide a comparative analysis of the options that will support the selection of an approach to development of the Advanced Computer System by FAA. The analysis is summarized in Table V-1.

V.5.1 Schedule

Schedule differences in the far term options appear to be marginal, the only apparent factor being the number of steps in the options due to the presence of an interim system or incremental development and implementation of the replacement system. It is worth noting, however, that Option 5 would delay the development of new software for the replacement system in favor of early deployment of the new hardware. Option 5 would also delay full operation of the Advanced Computer System functions until 1994 or 1995.

For the full replacement options (6 and 7) capacity relief can be provided relatively early by an appropriately selected near term option (Section IV). This appears to be necessary even in the case of the two-step replacement (Option 6), where it has been suggested that the initial step could provide the early capacity relief. In that case it appears that the onset of delay days would still occur before the initial step could be completed.Similarly, the interim system approaches will not be able to provide capacity relief as early as other capacity enhancement options and there is also a risk of meeting the interim system schedules.

An important caveat in the schedule analysis for the interim system options is the assumption that the entire program up to and including implementation of the Advanced Computer System can be accomplished in one procurement. If multiple procurements are required then schedule estimates for these options would have to stretch out.

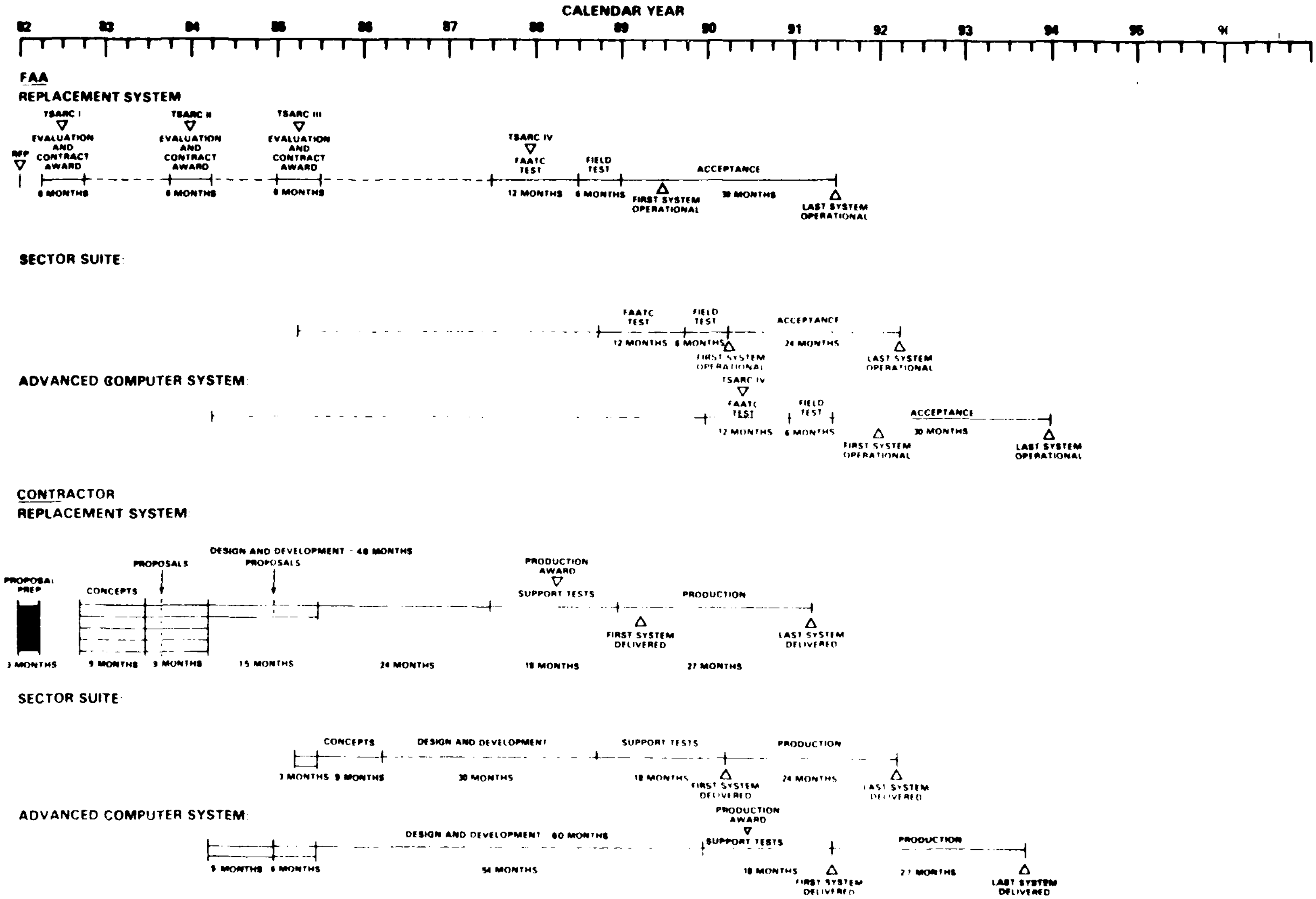


Figure V-11. Schedule for Option 7_, Single Step Transition to Replacement System (...)

TABLE V-1

EVALUATION OF FAR TERM OPTIONS

	INTERIM			NO INTERIM	
	5	8A	8B	6	7
SCHEDULE	A93*	R90 A92	R90 A92	R89-91** A93	R89** A92
COST	1.50B	1.39B	1.45B	1.38B	1.39B
RISK	LOW	ARCHITECTURE MAY CONSTRAIN DESIGNS FOR HIGHER LEVELS OF AUTOMATION		SOFTWARE SPLIT	LOW
IMPACT ON FAA RESOURCES	MED-HIGH	HIGH	HIGH	HIGH	MED
ABILITY TO EVOLVE	***	MED	MED	MED	***
TRANSITION IMPACT	MED-HIGH	HIGH	HIGH	HIGH	MED

*ACS SYSTEM IS AVAILABLE, BUT ADVANCED AUTOMATION WILL NOT BECOME AVAILABLE UNTIL 94 or 95
**ASSUMES OPTION 2 OR OPTION 3 IF NEEDED (COST NOT INCLUDED)
***UNCONSTRAINED. WILL RESULT FROM DESIGN PHASE

The specific options that were evaluated and indicated herein, reflect the concerns identified in the Congressional Recommendations. [illegible] the selected approach does not [illegible] in this table.

R-year of replacement system
A-year of A[illegible]

V.5.2 Cost

The costs for Options 5-8 are relatively close to one another, ranging from $1.33B to $1.52B. If one considers the need for an additional $20-100M for near term capacity solutions in Options 6 and 7, the range is even smaller. These marginal cost differences are not a signficant discriminant in selecting a far term option. Option 6 and 7 do of course entail additional costs (not included here) for throwaway interim hardware and software. Table V-2 summarizes the Replacement System and ACS costs.

V.5.3 Risk

There is a risk that the interim replacement computer that could execute the existing software in Option 8 may constrain the designs for higher levels of automation, particularly in the area of reliability requirements for functional improvements 10 and 11. Hence, augmentation/replacement of the Host hardware will be required in the ACS step.

The Option 8 interim is a particular concern because selection of a single contractor for the interim system, replacement system, and AERA is made very early, i.e., after six months of design study.

In the case of Option 6, the multi-step transition to replacement, a technical risk trade-off is involved. The replacement system is developed and implemented incrementally in an attempt to minimize risk involved in the individual steps. This is accomplished at the possible expense of a longer overall completion time for the full replacement. It may require that elements of the 9020 remain in service for a longer period of time than would be required by other options.

It appears that the direct replacement options involve the least overall risk to the replacement/advanced automation program objectives if the near term problems with the en route computers can be separately resolved, i. e., essentially independent of the Advanced Computer System procurement. However, in terms of minimum risk for the Advanced Computer System above, Option 5 delays the introduction of advanced automation to allow an integrated design and development of the basic and advanced functions, whereas other options call only for an integrated design of the basic and advanced functions with separate development of the advanced functions.

V.5.4 Impact on FAA Resources

The multiple step programs have potentially the greatest impact on overall FAA in-house resources. Among these, the interim system followed directly by replacement with the Advanced Computer System appears to be the least disruptive. However, the minimum impact on FAA in-house resources over all options seems to be the direct, one-step replacement

LONG TERM OPTIONS

COST SUMMARY

(1981 $)

OPTION	AERA	REPLACEMENT	TOTAL
5	795.8	705.9	1501.7
6	379.9	1002.4	1382.3
7A	439.2	1081.6	1520.9
7B	364.9	966.3	1331.2
7C	376.4	1008.8	1385.2
8A	469.6	920.7	1390.3
8B	540.9	911.9	1452.8

Table V-2. Long Term Options Cost Summary

V.5.5 Ability to Evolve

Interim system options that retain the interim system architecture may constrain ability to evolve because they impose the IBM 360 mainframe type architecture and associated large, all-purpose operating systems on the advanced system. Augmentation/replacement of the Host hardware will be required in the ACS step to overcome this constraint. The option which treats the interim system as a throw-away is essentially unconstrained in terms of its ability to evolve toward higher levels of automation and to adapt to new technology. The same is true for the single-step, direct replacement option, because it is not tied to any previous architecture. It is somewhat less true for the two-step, direct replacement since some constraints may be placed on the new architecture in order to accommodate the initial step interface with the existing system.

V.5.6 Transition Impact

This evaluation must be made in terms of the number of development and implementation steps involved in each of the programs and the relative amount of potential disruption implied by each step. The more transition steps required, the more opportunities there are for disruption of the operational ATC facilities. These considerations have to be weighed carefully against the advantages or requirements for having multiple-step programs to determine whether or not these needs warrant tolerating the additional transition impact of the multiple-step programs.

Some steps are clearly more disruptive than others. Stepwise replacement (Option 6) attempts to minimize the impact of individual steps by piecewise replacement of the hardware and software at the expense of a longer overall program. In the case of Option 8, sub-option 8a involves augmentation of the interim system hardware when implementing the advanced function software, whereas sub-option 8b involves complete replacement of the interim system hardware when implementing the advanced function software.

V.6 Benefit Cost Results of Far Term Options

V.6.1 Background

The material in Section IV.6 on the near term options describing the background, methodology and guidelines used in the benefit cost analysis is equally applicable to this Section, 6, on the far term options.

V.6.2 Costs

The benefit and the cost categories for the far term options shown in Tables V-3 and V-4 are identical, and therefore directly comparable, to those used in the analysis of the near term options.

TABLE V-3

DISCOUNTED BENEFITS
(billions of dollars - 1981)

OPTION	DELAY	FUEL	MAINT.	CONTROLLER	TOTAL BENEFITS
5	1.80	4.77	0.07	1.86	8.50
8A	1.80	4.85	0.07	1.98	8.70
6	1.68	4.85	0.05	1.98	8.56
7A	1.73	4.85	0.06	1.98	8.62
7B	1.75	5.05	0.06	1.98	8.84
7C	1.75	5.05	0.06	1.98	8.84

TABLE V-4

DISCOUNTED COSTS

(billions of dollars - 1981)

OPTION	COMPUTER REPLACEMENT	MODE S GROUND	MODE S AVIONICS	OTHER*	TOTAL COSTS
5	0.82	0.13	0.25	0.31	1.51
8A	0.81	0.13	0.25	0.31	1.50
6	0.70	0.13	0.25	0.31	1.39
7A	0.80	0.13	0.25	0.31	1.49
7B	0.72	0.13	0.25	0.31	1.41
7C	0.78	0.13	0.25	0.31	1.47

* Consists of:
Conflict Alert for IFR/VFR, Conflict Resolution Advisories, En Route Metering, Electronic Tabular Displays, Mode S Interface, Central Weather System Interface, and Terminal Information Display System

V.6.2 Results Obtained

The discounted benefit to cost ratios and the discounted benefit minus cost differences of the seven far term options described in Section V-4 are shown in Table V-5. All of the far term options provide good benefit to cost ratios as well as significant benefit to cost differences.

The discounted benefit/cost differences and the discounted benefit/cost ratios do not provide a significant enough discriminant among the far term options because they are so similar. The choice among the far term options must therefore be based on other considerations.

It is unreasonable to attempt a comparison of the cost benefit of the near and long term options since the two are based on quite different sets of requirements. It is unlikely that FAA will, in the near future, select a program that severely limits its ability to provide efficient and productive ATC service to all who desire it. The 'onger programs of options 5-8 have higher costs spread over a longer period but show, overall significantly higher benefits than the near term options. The difference between discounted costs and discounted benefits is much greater for the far term options that meet all of FAA's requirements than for the near term, constrained options. The result is a significant economic discriminant in favor of the far term options.

TABLE V-5

DISCOUNTED SUMMARY

(billions of dollars - 1981)

OPTION	TOTAL BENEFIT	TOTAL COST	B/C RATIO	B-C
5	8.50	1.51	5.6	6.99
8A	8.70	1.50	5.8	7.20
6	8.56	1.39	6.2	7.17
7A	8.62	1.49	5.8	7.13
7B	8.84	1.41	6.3	7.43
7C	8.84	1.47	6.0	7.37

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APPENDIX — 2

OPERATIONAL DELAY DAY FORECASTS

FOR THE TWENTY AIR ROUTE TRAFFIC CONTROL CENTERS

FOR THE YEARS 1982 THROUGH 2011

EXECUTIVE SUMMARY

During the first 6 months of 1981, FAA conducted an analysis to determine the capability of each 9020 system to accommodate forecast traffic growth and the addition of new automation functions.

The 9020 ON-LINE CENTRAL PROCESSING UTILIZATION MONITOR measures the average minute-by-minute percent of central processing capability utilized along with the track and flight plan load imposed on the computer. These data were collected for each ARTCC for a 4-7 day period between June 1980 and January 1981.

A regression analysis of these data showed that a linear relationship, within practical limits, exists between the number of tracks being processed and the 9020 computer capacity necessary for that processing at each site.

This information was correlated with FAA traffic forecasts to determine the amount of 9020 processing capacity needed to satisfy future traffic demand.

Experience with the ATC system makes it clear that processing capacity shortfalls manifest themselves as delays to air traffic.

With this information in hand, FAA set up a metric called an Operational Delay Day. This was defined as a day when 9020 processor utilization was forecast to exceed 80% of the available capacity for a sustained period of greater than one hour after all steps had been taken at the ARTCC to alleviate the processing load. (These steps include cessation of all recording and simulation training). FAA then estimated the total Operational Delay Days for the period 1982 through 2011. The results showed that eight ARTCC's (Denver, Houston, Miami, Okland, Albuquerque, Minneapolis, Memphis, and Seattle) would experience a substantial number of operational delay days during the mid and late 1980s (Table 1-1).

The FAA currently has a number of initiatives underway to relieve the 9020A processing capacity problems. The most effective of these early initiatives is offloading of some processing to the current input/output control elements (IOCE Offloading). The total achievable capacity buy-back from all the initiatives was conservatively estimated at 30%. This revised 9020 processing capacity was then extrapolated again and a substantial reduction in the number of Operational Delay Days was predicated for 1989 as illustrated in Table 1-1, Column II). Only Denver, Houston, and Miami would still experience a substantial number of Operational Delay Days.

The FAA, in addition to providing for capacity growth, desires to functionally enhance the 9020 system during the 1980s. These planned improvements would provide for further increases in safety (Conflict Alert for VFR Intruders and Conflict Resolution Advisories); for fuel savings (En Route Metering); and for productivity increases (the electronic tabular display capability in the sector suite).

Center	Computer Complex	Forecast Year of Onset of > 2 Operational Delay Days 3d2.9/10 Baseline	Operational Delay Days For 1989		
			I. Baseline	II. Baseline + 30% Buyback	III. Baseline + 30% Buyback + Functional Improvement
Albuquerque	9020A	1983	205	-	2
Atlanta	9020D	2002	-	-	-
Boston	9020A	1989	4	-	-
Chicago	9020D	1998	-	-	-
Cleveland	9020D	2001	-	-	-
Denver	9020A	Current	331	39	237
Fort Worth	9020D	2007	-	-	-
Houston	9020A	Current	252	75	176
Indianapolis	9020D	2003	-	-	-
Jacksonville	9020D	Beyond 2011	-	-	-
Kansas City	9020D	2011	-	-	-
Los Angeles	9020D	1997	-	-	-
Miami	9020A	Current	311	24	105
Memphis	9020A	1986	152	-	2
Minneapolis	9020A	1985	147	-	5
New York	9020D	2002	-	-	-
Oakland	9020A	Current	227	2	51
Salt Lake City	9020A	1990	2	-	-
Seattle	9020A	1986	105	-	-
Washington	9020D	Beyond 2011	-	-	-

Table 1-1 Operational Delay Days

impact of adding these improvements to the 9020 system was also analyzed (as shown in Table 1-1, Column III).

In summary, the FAA has sufficient initiatives underway to adequately handle its near term processing capacity problems at the 9020A sites. However, to accommodate increased traffic, to implement needed functional improvements, and to assure full service to users in the late 1980s, it will be necessary to take additional actions.

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SUMMARY

The effect of forecasts of increased traffic growth at each of the twenty CONUS Air Route Traffic Control Centers has been examined to determine the impact upon processor utilization of the Central Computer Complex at each center. Other factors such as channel utilization are not included in this phase of the study, but their effects will be determined as data become available. This study assumes continuation of the current operational capabilities and procedures at each center. This study is based upon data collected between June 1980 and January 1981, under program versions 3d2.9 and 3d2.10 (without the IOCE offloading capability - see page 16).

The centers with 9020-A configurations are expected to be affected by increased traffic loads before those centers with 9020-D configurations. These increased traffic loads cause increased processor utilization which must be dealt with by using different procedures and, if conditions warrant, imposing air traffic delays in order to maintain a continued high level of safety. Of the A-sites, five may be expected to approach the processor utilization limit in the near future (within the next few years); three more A sites are forecast to approach the limits in the mid-80's, and two may not approach the limits until the late 80's.

The centers with 9020-D configurations do not become processor utilization bound until well into the 1990's or beyond. The results of the analysis are presented in summary form in Tables 1 and 2; the geographical distribution of impacted centers is presented in Figure 1.

In order to quantify the analysis, two metrics are defined. The results contained in Tables 1 and 2 and the conclusions of the report are expressed in terms of these two metrics.

An Operational Impact Day is defined to be a day during which the processor utilization exceeds 80% for a sustained period of greater than seven minutes. This is compatible with the operational procedures which call for a set pattern of cessation of selected support functions when the processor utilization exceeds 80% for a sustained period of greater than five minutes (GENOT, Reference 5). An Operational Impact Day is, then, a day when procedural cessation of selected support functions would be expected to occur at a center.

An Operational Delay Day is defined to be a day during which the processor utilization exceeds 80% for a sustained period of greater than one hour after all of the procedures of the GENOT are executed (with the exception of inclusion of the fourth processor in the 9020A's). Increase of the processor utilization beyond 80% results in slower output of necessary data to Air Traffic Controllers by the automation system. The Air Traffic Controllers restrict their requests to the automation system to essential services only and increase aircraft separation in order to continue to assure safety. In cases of a sustained period of computer overload, rerouting of en route aircraft around overloaded centers and restricting the flow of traffic into the

FORECAST YEAR OF ONSET OF OPERATIONAL DELAY DAYS	CENTER	Z CODE	CENTRAL COMPUTER COMPLEX	FORECAST YEAR FOR ONSET OF OPERATIONAL IMPACT DAYS
Current	Denver	ZDV	9020-A	Current
Current	Houston	ZHU	9020-A	Current
Current	Miami	ZMA	9020-A	Current
Current	Oakland	ZOA	9020-A	Current
1983	Albuquerque	ZAB	9020-A	Current
1985	Minneapolis	ZMP	9020-A	Current
1986	Memphis	ZME	9020-A	Current
1986	Seattle	ZSE	9020-A	1984
1989	Boston	ZBW	9020-A	1984
1990	Salt Lake City	ZLC	9020-A	1984
1997	Los Angeles	ZLA	9020-D	1991
1998	Chicago	ZAU	9020-D	1994
2001	Cleveland	ZOB	9020-D	1995
2002	Atlanta	ZTL	9020-D	1997
2002	New York	ZNY	9020-D	1993
2003	Indianapolis	ZID	9020-D	1997
2007	Fort Worth	ZFW	9020-D	1997
2011	Kansas City	ZKC	9020-D	2001
Beyond 2011	Washington	ZDC	9020-D	2005
Beyond 2011	Jacksonville	ZJX	9020-D	Beyond 2011

TABLE 1 - FORECAST OF THE YEAR OF ONSET (2 DAYS/YEAR) OF OPERATIONAL IMPACT DAYS AND OPERATIONAL DELAY DAYS BY CENTER

	FORECAST YEAR									
CENTER	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
ZAB	206	220	230	233	237	239	241	243	245	247
ZAU	-	-	-	-	-	-	-	-	-	-
ZBW	-	2	4	8	19	29	44	55	77	96
ZDC	-	-	-	-	-	-	-	-	-	-
ZDV	252	284	315	336	350	354	358	365	365	365
ZFW	-	-	-	-	-	-	-	-	-	-
ZHU	197	225	243	251	258	264	278	292	309	321
ZID	-	-	-	-	-	-	-	-	-	-
ZJX	-	-	-	-	-	-	-	-	-	-
ZKC	-	-	-	-	-	-	-	-	-	-
ZLA	-	-	-	-	-	-	-	-	2	6
ZLC	-	2	5	17	40	56	81	114	152	169
ZMA	149	201	267	315	343	351	359	365	365	365
ZME	38	89	137	192	214	231	239	243	247	250
ZMP	21	42	82	152	198	224	243	252	262	271
ZNY	-	-	-	-	-	-	-	-	-	-
ZOA	221	240	243	247	250	253	256	258	264	270
ZOB	-	-	-	-	-	-	-	-	-	-
ZSE	-	2	21	58	120	154	181	208	231	241
ZTL	-	-	-	-	-	-	-	-	-	-

TABLE 2A FORECAST OF OPERATIONAL IMPACT DAYS BY CENTER

FORECAST YEAR

CENTER	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
ZAB	2	5	24	48	104	141	178	205	223	230
ZAU	-	-	-	-	-	-	-	-	-	-
ZBW	-	-	-	-	-	-	2	4	6	11
ZDC	-	-	-	-	-	-	-	-	-	-
ZDV	31	77	152	218	264	291	313	331	342	351
ZFW	-	-	-	-	-	-	-	-	-	-
ZHU	39	68	114	169	214	237	247	252	257	262
ZID	-	-	-	-	-	-	-	-	-	-
ZJX	-	-	-	-	-	-	-	-	-	-
ZKC	-	-	-	-	-	-	-	-	-	-
ZLA	-	-	-	-	-	-	-	-	-	-
ZLC	-	-	-	-	-	-	-	2	5	14
ZMA	13	36	78	126	186	230	279	311	338	349
ZME	-	-	-	2	16	45	99	152	194	211
ZMP	-	-	2	8	26	51	90	147	192	218
ZNY	-	-	-	-	-	-	-	-	-	-
ZOA	42	70	100	140	173	193	211	227	241	243
ZOB	-	-	-	-	-	-	-	-	-	-
ZSE	-	-	-	-	7	30	64	105	142	164
ZTL	-	-	-	-	-	-	-	-	-	-

TABLE 2B FORECAST OF OPERATIONAL DELAY DAYS BY CENTER

NAS ENROUTE SYSTEM

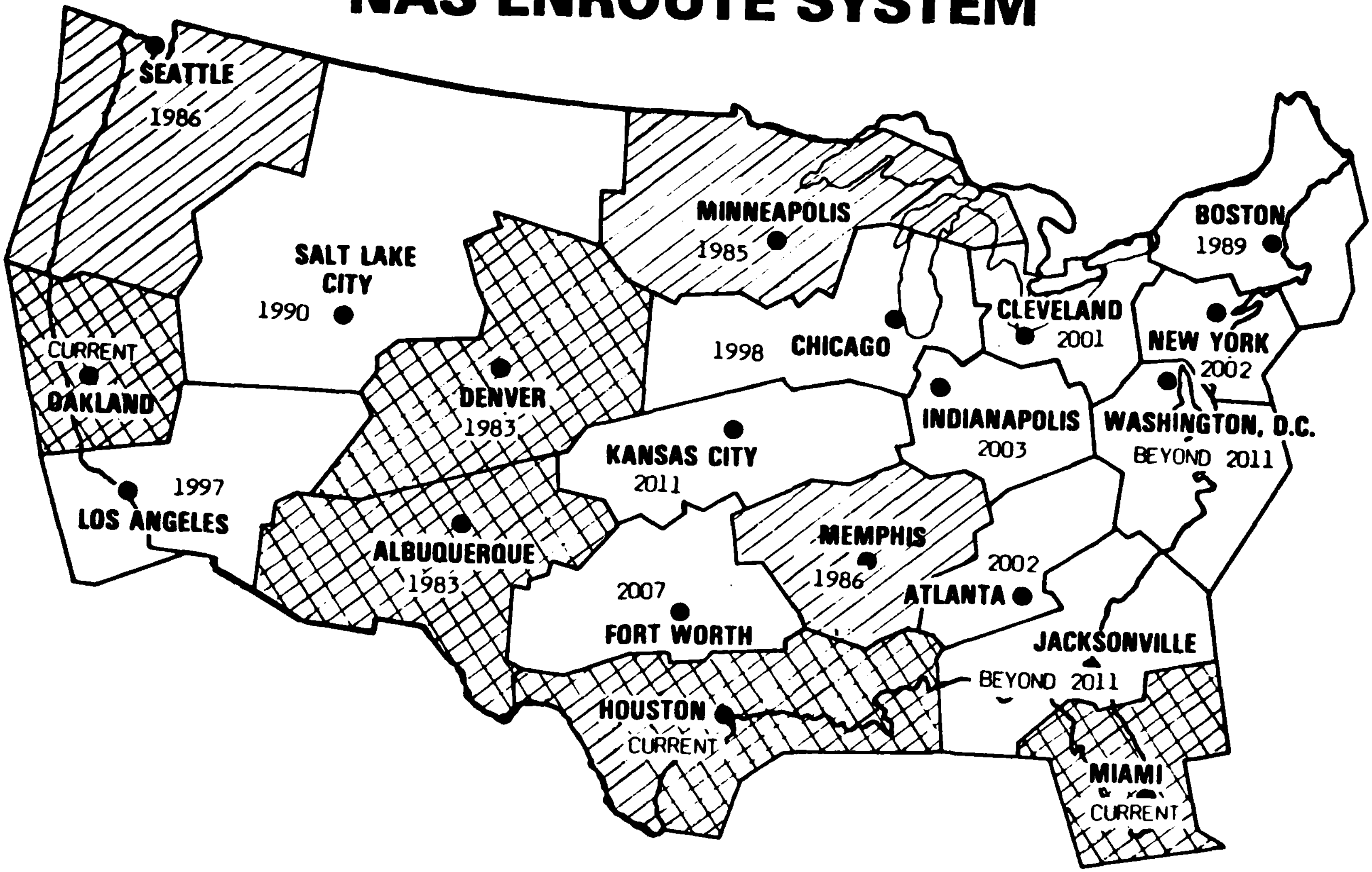

FIGURE 1 GEOGRAPHICAL DISTRIBUTION OF CENTERS SHOWING THE FORECAST FIRST YEAR WITH GREATER THAT TWO OPERATIONAL DELAY DAYS

overloaded center's airspace are used to restrict traffic to manageable load levels. An Operational Delay Day is, then, a day when the Air Traffic Control System is expected to impose air traffic delays on users due to automation system loading.

The assumptions of this analysis are consistent with those used in the traffic forecasts for each center to the year 2011. The net result of this analysis is that eight of the 9020-A sites can be expected to experience significant Operational Delay Days by the mid-80's unless some actions are taken to alleviate the situations at those centers.

Changes to the 9020 hardware and software system are currently being developed by the FAA in order to reduce processor utilization. A sensitivity analysis was thus performed assuming a 30% reduction in processor utilization, and is reported on page 16 in the section, "Further Analysis".

INTRODUCTION

Forecasts are only as valid as the assumptions used in deriving them. The generation of the forecasts of future Central Computer Complex utilization at each center relies upon available measured relationships in order to transform forecasts of the Peak Track Count (PTC) based on peak day IFR aircraft handled (Ref. 1) into the desired Central Computer Complex utilization forecast for each center for the period 1982 through 2011. The general methodology, including the assumptions underlying the steps, will be discussed first. The definitions and interpretations of the thresholds used in this study will then be presented. The results of the computations will conclude this discussion.

METHODOLOGY

The forecasts upon which the analysis is based are the Instantaneous Airborne Count forecasts for each center for the period 1982 through 2011, Reference 1. The transformations used to convert from the traffic forecasts to Central Computer Complex utilization forecasts include:

- o the correlation relationships between Processor Utilization, Active Flight Plans, and Tracks, reported in References 2 and 3.
- o the functions to be shed and the conditions under which they are to be shed, presented in Reference 5.
- o the distribution of the number of days per year that the daily air traffic handled by a center will exceed a specified fraction of the yearly maximum value of daily air traffic handled by that center.
- o the ratio of the maximum peak track count on a given day to the total number of IFR aircraft handled by that center on that day.
- o the time distribution of aircraft traffic handled across the day for each center. An example is presented in Figure 2; data for all of the centers is contained in Reference 4.

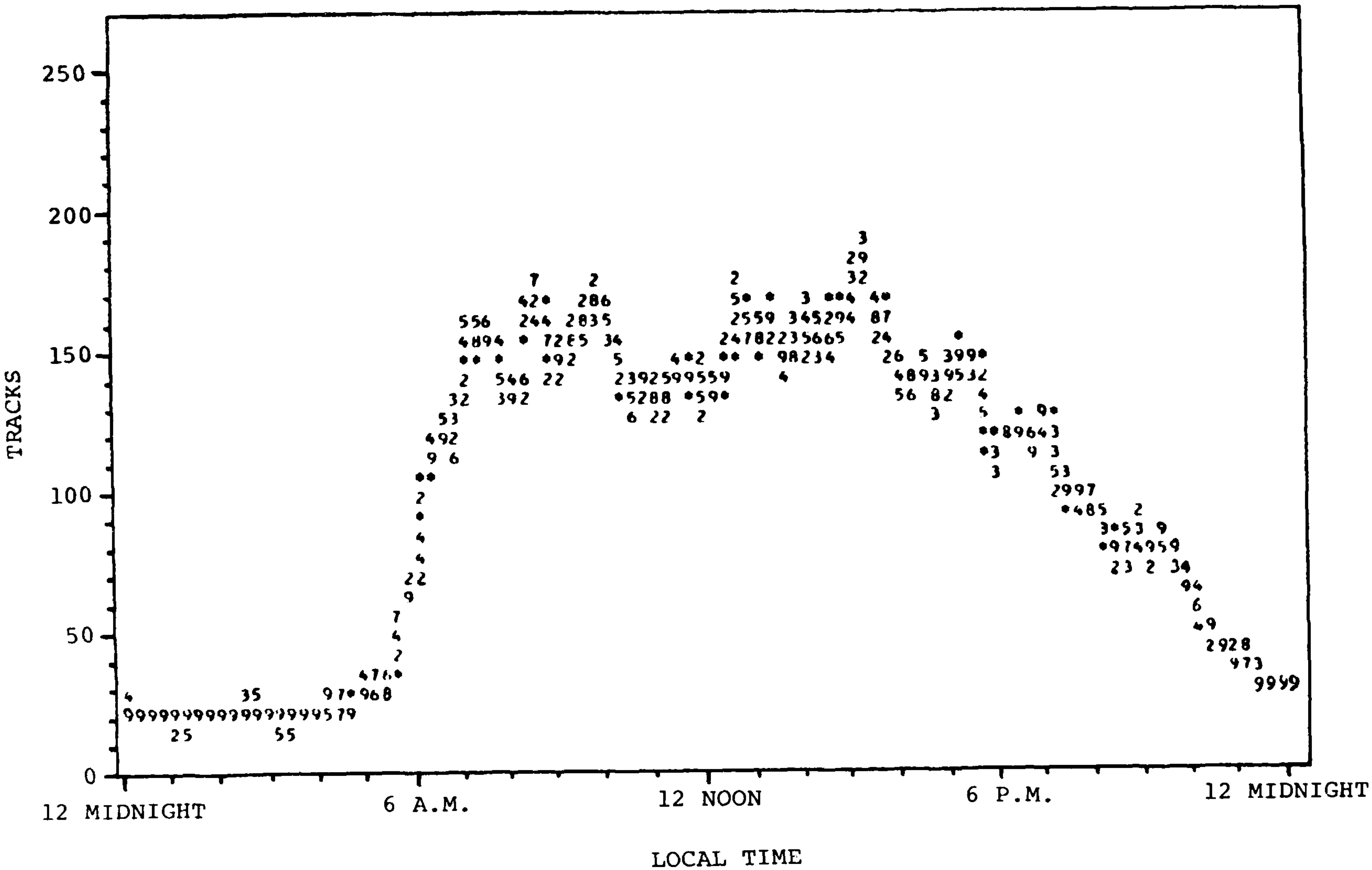

FIGURE 2 DISTRIBUTION OF AIRCRAFT TRACKS HANDLED AT HOUSTON ON JUNE 18, 1980

One of the basic assumptions made in this analysis is that the ratios and relationships among the above parameters will be relatively constant. The aircraft activity forecasts do not predict radical changes in the traffic patterns, so that it is unlikely that the above parameters will vary greatly from the values observed for them in recent years for the busiest days of the week. That is, the use of the above ratios and relationships is consistent with the assumptions used in the forecast generation (Ref. 1).

Part of the Central Computer Complex software consists of monitoring tools that can record a number of system performance observations during live ATC operations. The ON-LINE CENTRAL PROCESSING UTILIZATION MONITOR represents one of the available system monitoring tools. It was used in this study to collect for each minute the average percent of central processing consumed along with the track and flight plan load imposed on the computer.

The linear relationship found by Press (Ref 2, 3) between tracks and processor utilization provides a mapping between these two variables. The data was gathered under constant operating conditions at each center. The results show a linear correlation between the number of tracks reported in the Central Computer Complex and the processor utilization of the Central Computer Complex. It is expected that this relationship will vary as the system enters saturation at high values of processor utilization, but the empirical results indicate that the linear relationship extends up to the vicinity of 80% processor utilization, which is sufficient for the purposes of this study.

Table 3 presents pertinent parameters from that analysis. The deviations in the data collection conditions are listed, along with the values for the high end of the processor utilization range observed in that analysis. As can be seen, the measurements indicating the linear relationship between processor utilization and aircraft being tracked extend beyond values of 80% processor utilization for those centers of greatest interest to this study. The definition of the two metrics, the number of Operational Impact Days and the number of Operational Delay Days, is dependent only upon the observed properties below an 80% processor utilization for which the linear relationship has been demonstrated.

The FAA General Notice (GENOT, Reference 5) states the order of cessation of selected support functions to be accomplished when the processor utilization for the Central Computer Complex at a center exceeds 80% for a sustained 5-minute period. The steps to be taken, in the order specified in the GENOT, are:

- TURN OFF TIMING ANALYSIS REPORT SYSTEM (TARS)
- TURN OFF RESOURCE MONITORING (REMON)
- REDUCE SYSTEM ANALYSIS RECORDING (SAR) TO LOWEST LEVEL
- ADD THE FOURTH COMPUTE ELEMENT TO THE OPERATIONAL CONFIGURATION (AT THE 9020-A SITES; DSS JUDGEMENT)
- TURN OFF SYSTEM ANALYSIS RECORDING
- TURN OFF ARRIVAL DELAY RECORDING (ADR)
- TURN OFF DISPLAY INTERFACE RECORDING (DLOG)
- TURN OFF TRAINING SIMULATION (DYSIM)

CENTER	PROGRAM VERSION	DATA GATHERING PERIOD	UPPER RANGE OF PROCESSOR UTILIZATION OBSERVED	SYSTEM STATE DEVIATIONS DURING DATA GATHERING	CORRELATION RELATION PARAMETERS SLOPE	INTERCEPT
ZAB	3d2.9	JUNE '80	91	TARS PROCESSING ON, TARS RECORDING OFF	0.338	10.17
ZAU	3d2.10	JAN '81	45		0.147	4.94
ZBW	3d2.9	JULY '80	68	TARS PROCESSING ON, TARS RECORDING OFF	0.417	8.36
ZDC	3d2.9	JULY '80	58		0.148	5.12
ZDV	3d2.10	AUG '80	85		0.268	16.89
ZFW	3d2.10	DEC '80	50		0.145	4.61
ZHU	3d2.9	JUNE '80	88		0.415	7.50
ZID	3d2.9	JULY '80	42		0.161	3.43
ZJX	3d2.9	JUNE '80	40	TARS PROCESSING ON, TARS RECORDING OFF	0.149	5.77
ZKC	3d2.9	JULY '80	35		0.134	5.23
ZLA	3d2.9	JUNE '80	40	TARS ON	0.224	1.75
ZLC	3d2.9	JUNE '80	68		0.277	12.25
ZMA	3d2.9	JUNE '80	75		0.390	8.50
ZME	3d2.9	JULY '80	80		0.287	10.50
ZMP	3d2.9	JUNE '80	80		0.336	13.54
ZNY	3d2.9	JULY '80	71	TARS ON, SAR FULL	0.247	6.51
ZOA	3d2.10	OCT '80	87		0.384	12.12
ZOB	3d2.9	JUNE '80	55		0.168	4.27
ZSE	3d2.10	OCT '80	55		0.292	10.02
ZTL	3d2.9	JULY '80	46		0.153	5.65

TABLE 3 SIGNIFICANT PARAMETERS FROM THE CORRELATION ANALYSIS (References 2, 3)

While the functions deleted have lower priority than those utilized in maintaining aircraft separation, the cessation of these functions removes valuable record keeping and analysis activities.

The effects on the processor utilization of the first three of these GENOT steps are incorporated in the data gathered for the correlation analysis, except for those cases noted in Table 3. Addition of the fourth Compute Element to the operational configuration at the 9020-A sites is specified in the GENOT to be a Data System Supervisor judgement, and is not included in this study. The inclusion of the fourth Compute Element in order to get a gain in available processor utilization risks an outage if one of the Compute Elements fails. The procedures for adding the fourth Compute Element are in preparation.

It is not required for the purposes of this study to determine the amount of processor utilization saved by each of these actions (the buy-back due to cessation of selected support functions); the total amount for all steps is sufficient. The 80% processor utilization value listed in the GENOT is used to define a set of thresholds, as will be detailed in the following sections.

Based on cursory analysis and discussions with FAA personnel, a 12% processor utilization buy-back has been used in this study, which constitutes a realistic value for the savings for the last four steps on the GENOT list. Because of the removal of all status monitoring recording during such cases, measurement of this value would prove difficult. Several independent estimates indicated that the value could be in the 12% range. As the value is optimistic, it can be safely assumed that centers still indicated to be in difficulty after the cessation of selected support functions do require further detailed consideration.

The last set of relationships required for this analysis depends upon the assumption that the slowly varying behavior of yearly changes in aircraft handled can be interpreted as an indication that distributions do not radically alter. Several of these are of interest:

a) the number of tracks in the Central Computer Complex as a function of time-of-day

b) the ratio of the peak number of tracks in the Central Computer Complex for a day to the number of IFR aircraft handled that day

c) the cumulative distribution of the IFR aircraft handled over the year normalized by the peak day IFR aircraft handled for the year.

An example illustrating the distribution of tracks at a center as a function of time-of-day is presented in Figure 2. Evaluation of the available data indicates the existence of a characteristic shape of the distribution for each center. The distribution across the day at each center reflects the distribution and scheduling of IFR aircraft flights crossing that center, and thus is expected to change slowly with time.

The latter relationship, the normalized cumulative distribution of the IFR aircraft handled, is found by forming the ratio of the daily IFR aircraft handled to the peak day IFR aircraft handled, and ordering the ratios by decreasing value of the ratio. This yields a function which specifies, for a given value of the ratio, the number of days for which the IFR aircraft handled was equal to or greater than that fraction of the peak day IFR aircraft handled. Let x denote the ratio:

$$x = \frac{\text{daily IFR aircraft handled}}{\text{peak day IFR aircraft handled}} .$$

If the ratio of the peak number of tracks in the Central Computer Complex for a day to the number of IFR aircraft handled for that day is roughly a constant, then the normalized cumulative distribution may be expressed in terms of the ratio of the Peak Track Count (PTC) for the day of interest to the Peak Track Count for the peak day of the year, so that now

$$x = \frac{\text{PTC for the day of interest}}{\text{PTC for the peak day of the year}} .$$

A sample normalized cumulative distribution is presented in Figure 4. The consistency of the shapes of the distributions between centers is illustrated in Figure 3. The distributions are composed of two plateaus, one extending from about 20 days to about 250 days, and a second from about 250 days to 360 days. The first plateau generally represents the traffic handled on week days; the second plateau generally represents the traffic handled on weekends. The distribution of travel patterns within a week are not expected to vary greatly.

The number of days for which a center's processor utilization requirements may be expected to exceed some threshold can be found by converting the threshold to track equivalent using the observed correlation relations and determining the position on the distribution curve.

$$\text{track equivalent} = \frac{\text{threshold} - \text{intercept}}{\text{slope}} .$$

Let m and b denote the empirically determined slope and intercept from the correlation relations determined for each center, and C the desired processor utilization threshold value. The expression becomes

$$\text{track equivalent} = T = \frac{C - b}{m} .$$

Let the normalized cumulative distribution be denoted by g(x). The value of the distribution is then given by

$$g = \frac{\text{track equivalent}}{\text{peak day PTC}} = \frac{T}{\text{PTC}} = \frac{C - b}{m * (\text{PTC})} .$$

where PTC is now taken to refer to the peak day PTC for the year under consideration. With the value of the distribution g determined, the corresponding number of days which are expected to exceed this value can be picked from the observed normalized cumulative distribution for the

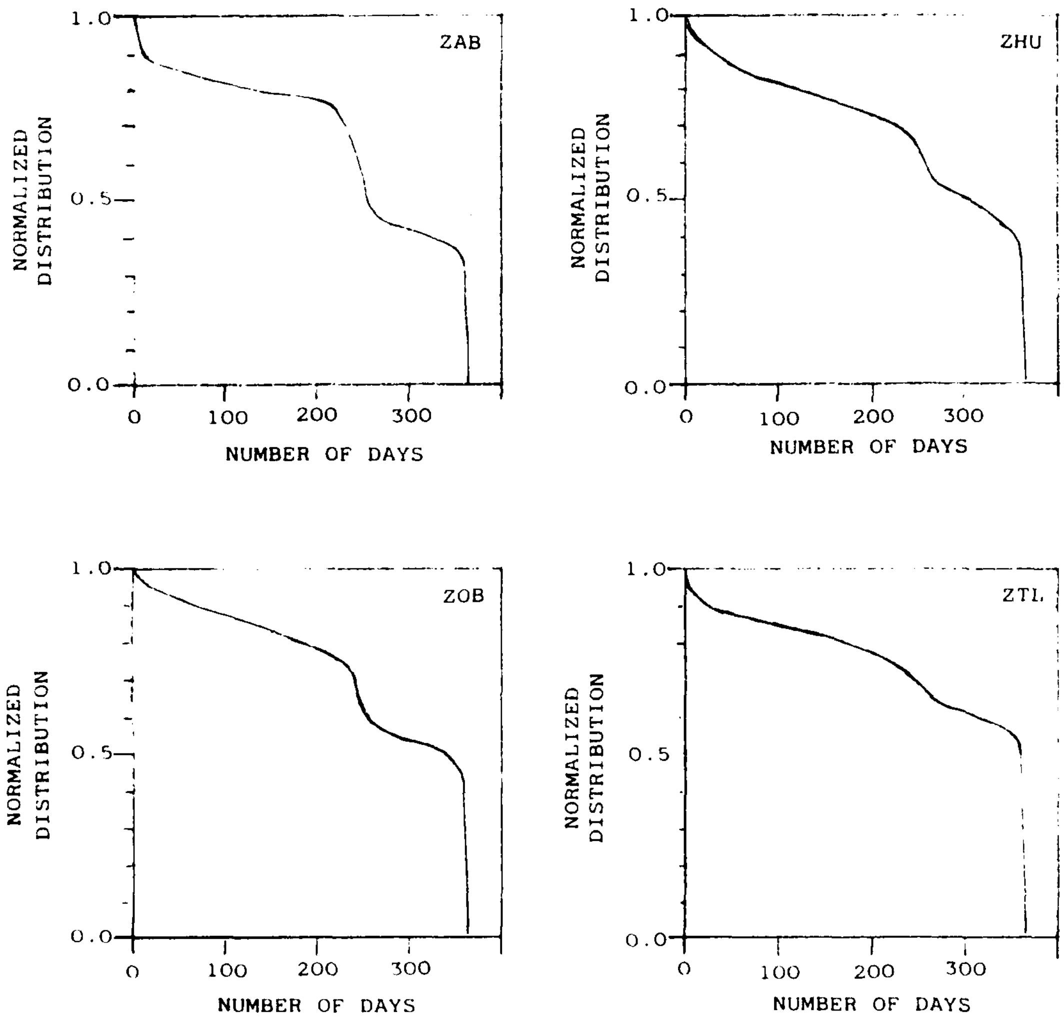

FIGURE 3   NORMALIZED DISTRIBUTIONS OF THE NUMBER OF AIRCRAFT HANDLED OVER A PERIOD OF ONE YEAR AT SEVERAL REPRESENTATIVE ARTCC'S

$$\frac{T_{80}}{PTC} = \frac{175}{238} = 0.735, \ D>80\% = 196$$

$$\frac{T_{80'}}{PTC} = \frac{211}{238} = 0.887, \ D>80'\% = 39$$

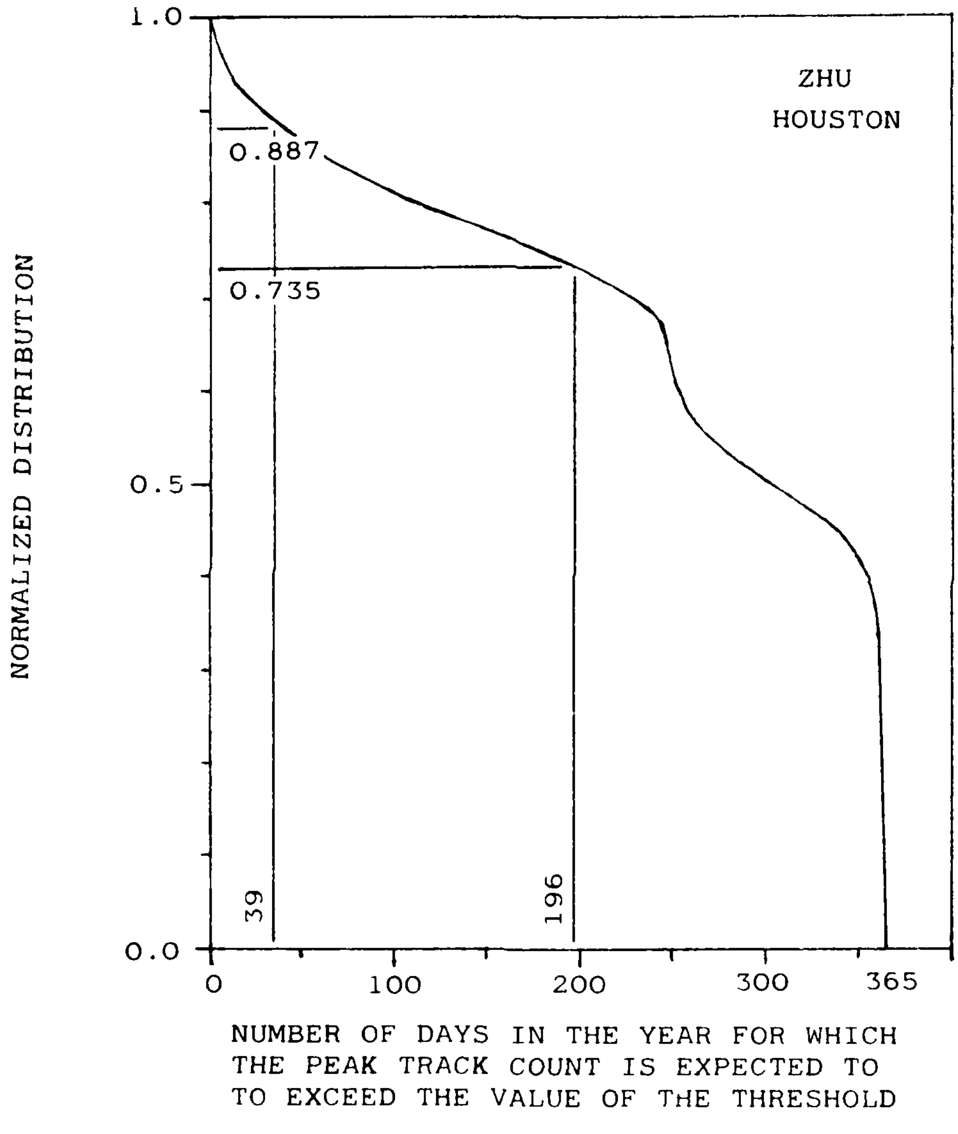

FIGURE 4 DETERMINATION OF THE NUMBER OF OPERATIONAL DELAY DAYS AND THE NUMBER OF OPERATIONAL IMPACT DAYS

center, as illustrated in Figure 4. Here T_{80} is the track equivalent corresponding to a processor utilization threshold C of 80%, the value of the utilization used in the definition of Operational Impact Day.

When buy-back is included, the processor utilization threshold must include the appropriate terms for the buy-back. Let the total threshold be given by:

$$C = TH + BB + DL$$

where TH = threshold level in percent

BB = buy-back processor utilization value in percent

DL = delay affect.

For this study, the threshold level TH is 80% (corresponding to the value in the GENOT), the buy-back processor utilization BB is 12% (corresponding to the processor utilization gain assumed for the completion of cessation of selected support functions), and the delay effect DL (the amount of processor utilization advantage gained by accepting operational impact for a specified time duration) must be determined for each center. Values for DL for the centers range between 0% and 4% assuming that the first hour of computer overhead can be absorbed by the center operations.

The general case is then

$$g(x) = \frac{TH + BB + DL - b}{m * (PTC)} ,$$

where x represents the number of days for the year for which the maximum processor utilization usage is expected to exceed the threshold C.

T_{80}' in Figure 4 corresponds to this relationship with

$TH = 80\%$

$BB = 12\%$

DL = value determined for each center

m, b = values determined for each center in the correlation analysis.

Saturation onset occurs when $g(x) = 1$. Solving for the corresponding value of PTC for $g(x) = 1$:

$$PTC = \frac{TH + BB + DL - b}{m} .$$

The year for which the forecast PTC has this value corresponds to the year when the specified threshold is first exceeded.

Thereafter, g can be estimated from

$$g(x) = \frac{TH + BB + DL - b}{m * (PTC)} ,$$

and the number of days x for which the threshold is exceeded can be estimated from the observed normalized cumulative distributions, as in Figure 4.

A calculation of one of the data points may be the best way to provide an understanding of the analysis methodology. Houston center in 1982 is selected as the example. The forecast peak track count for Houston in 1982 is 238 tracks (reference 1). From Table 3 the mapping between processor utilization and tracks is:

$$\text{processor utilization} = 7.50 + 0.415 * \text{TRACKS}.$$

Using this relationship, the 80% processor utilization threshold specified in the GENOT is found to be 175 tracks. Thus, cessation of selected support functions is expected to be called for when the automation system track load exceeds 175 active aircraft tracks for Houston center. This constant is denoted by T_{80}.

A second constant, T_{80}', is also defined. This constant corresponds to the number of tracks in the system when the processor utilization reaches 80% for a sustained period of one hour after the cessation of selected support functions specified in the GENOT is accomplished.

The buy-back in processor utilization as a result of the specified cessation of selected support functions is estimated to be 12%. Examination of the distribution of active tracks across a busy day for Houston indicates that a one-hour absorption of computer saturation is equivalent to a buy-back of about 3%. The equivalent threshold is then 80% + 12% + 3% = 95%. The corresponding number of tracks, found by solving the correlation relationship, is 211 active tracks.

The two threshold values, divided by the forecast maximum Peak Track Count for the year, gives the normalized distribution values corresponding to the two thresholds.

$$\frac{T_{80}}{PTC} = \frac{175}{238} = 0.735, \qquad \frac{T_{80}'}{PTC} = \frac{211}{238} = 0.887.$$

These values are entered in the normalized cumulative distribution for Houston, given in Figure 4, and the corresponding number of days exceeding the criteria are determined from the curve.

RESULTS

The results of this analysis are summarized in Figures 5 and 6. Plotted here are the number of Operational Delay Days for each center for each year in the projection period. The centers with 9020-D complexes do not have potential processor utilization problems until late in the forecast period. Eight of the 9020-A complexes indicate the onset of processor utilization problems in the early to mid-1980's.

The curve for each center has two characteristics of interest, the year of the delay onset and the rate of increase thereafter. The year of delay onset depends upon the values of all of the constants used in the analysis. The rate of increase after onset, however, is dependent mainly upon the forecast yearly traffic increase and the shape of the normalized distribution function for each center. The shape of the normalized distribution is not likely to change markedly; thus, once the threshold is passed and Operational Delay Days start for a center, it may be expected that the number of Operational Delay Days will increase rapidly over a short interval of years.

The year of onset depends upon the assumed stability of several relationships and the number of aircraft in the traffic forecasts. The near-term forecast values may be expected to be accurate, thus centers which are expected to enter problem times in the near term have a good probability of being properly identified.

FURTHER ANALYSIS

It should be emphasized that this analysis is based on the data collected and analyzed in References 2, 3, and 4. The FAA is making changes to the 9020 hardware and software system to reduce processor utilization. The most notable of these is an extra storage element added to the Central Computer Complex and the offloading of some processing to the Input-Output Compute Element in software version 3d2.10. Data is being collected to measure these gains and will be analyzed upon receipt.

However, in order to quantify possible gains in processor utilization as well as to provide a sensitivity analysis to the foregoing results, an additional analysis has been performed. This analysis was performed using an assumed value of 30% for the buy-back processor utilization (BB) in the expression for the normalized cumulative distribution g(x) (page 14), computing the new values of the distribution, and then determining the number of days for which the threshold is exceeded from the empirical curves.

The results of the analysis are shown in Table 4. The basic results remain unchanged but shifted in time. Four center's exhibit operational delays in the mid-1980's. A comparison with Table 2 shows that the onset of the impacts have been delayed, but that processor capacity problems will continue to plague the FAA at certain centers throughout the 1980's.

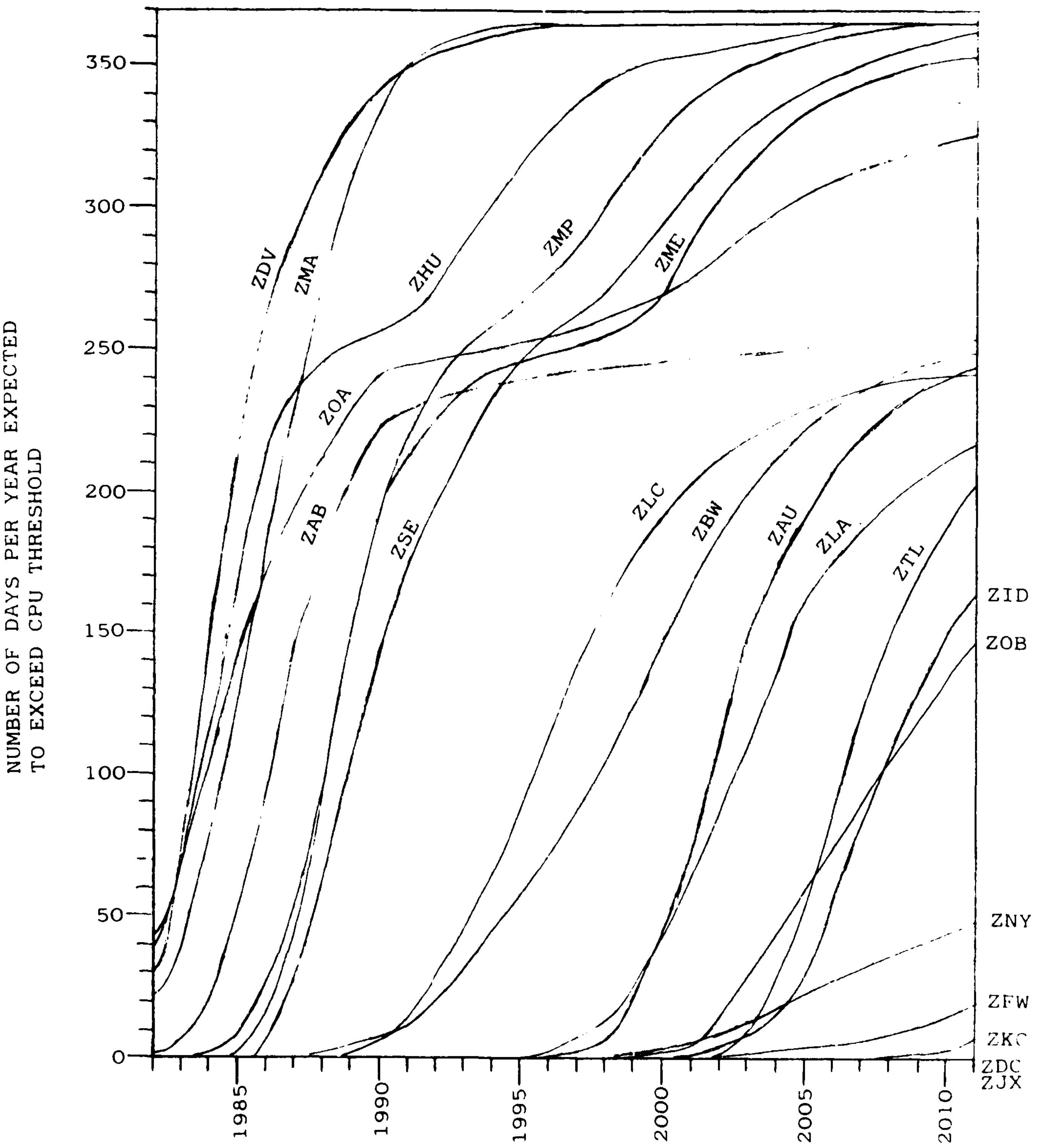

FIGURE 5 FORECAST NUMBER OF OPERATIONAL DELAY DAYS BY CENTER

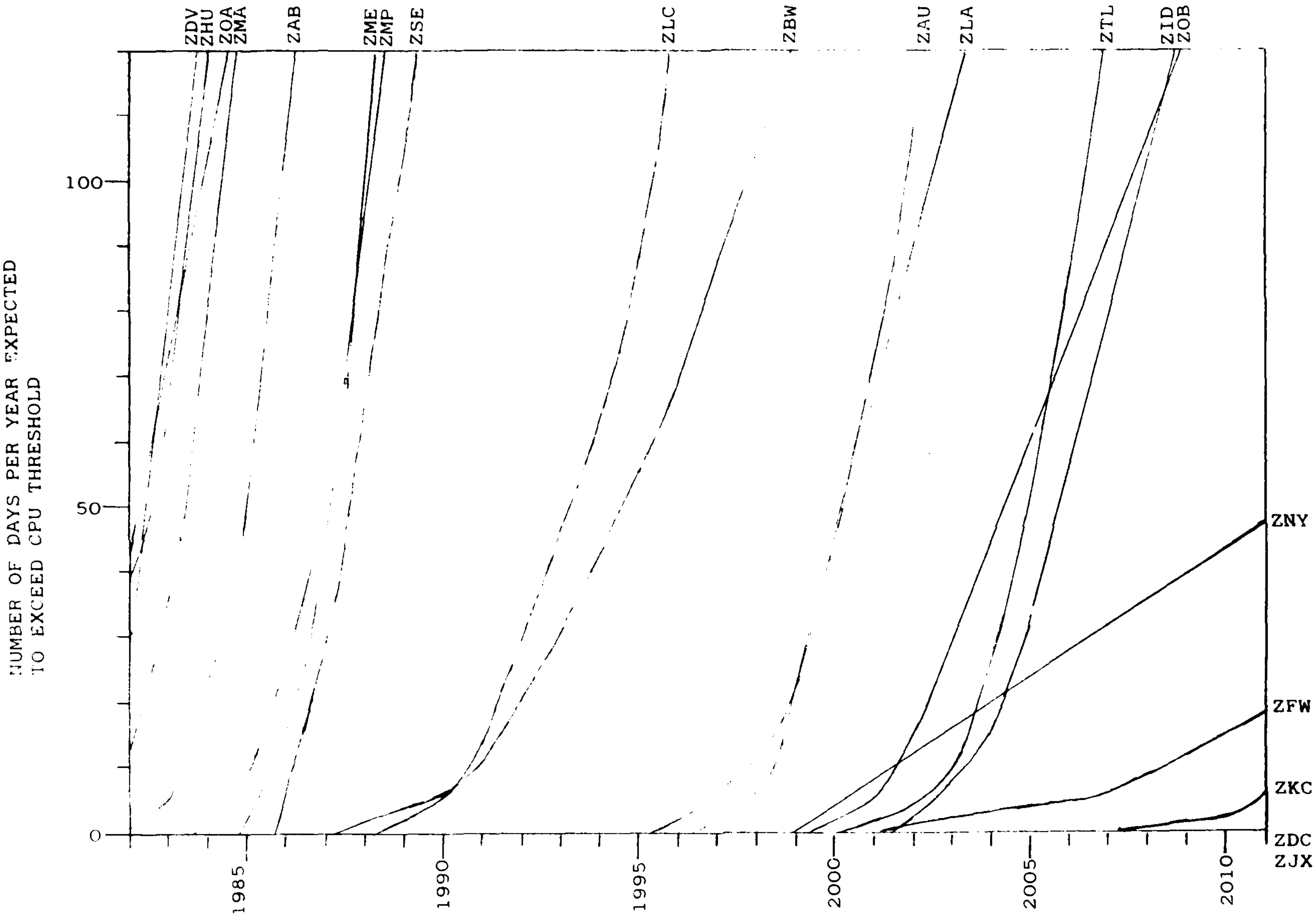

FIGURE 6 FORECAST NUMBER OF OPERATIONAL DELAY DAYS BY CENTER - DETAIL TO SHOW RATE OF GROWTH AT ONSET

	FORECAST YEAR									
CENTER	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
ZAB	-	-	-	-	-	-	-	-	2	2
ZAU	-	-	-	-	-	-	-	-	-	-
ZBW	-	-	-	-	-	-	-	-	-	-
ZDC	-	-	-	-	-	-	-	-	-	-
ZDV	-	-	-	-	2	5	19	39	85	139
ZFW	-	-	-	-	-	-	-	-	-	-
ZHU	-	-	-	-	8	21	47	75	124	160
ZID	-	-	-	-	-	-	-	-	-	-
ZJX	-	-	-	-	-	-	-	-	-	-
ZKC	-	-	-	-	-	-	-	-	-	-
ZLA	-	-	-	-	-	-	-	-	-	-
ZLC	-	-	-	-	-	-	-	-	-	-
ZMA	-	-	-	-	-	4	11	24	60	90
ZME	-	-	-	-	-	-	-	-	-	-
ZMP	-	-	-	-	-	-	-	-	2	2
ZNY	-	-	-	-	-	-	-	-	-	-
ZOA	-	-	-	-	-	-	2	2	21	29
ZOB	-	-	-	-	-	-	-	-	-	-
ZSE	-	-	-	-	-	-	-	-	-	-
ZTL	-	-	-	-	-	-	-	-	-	-

TABLE 4 SENSITIVITY ANALYSIS RESULTS FOR FORECAST OF OPERATIONAL DELAY DAYS BY CENTER

REFERENCES

Reference 1 Instantaneous Airborne Counts, A Preliminary Report of Studies Underway at the Office of Aviation Policy and Plans, Information Systems Branch, May 1981

FAA Forecast of Air Route Traffic Control Center IFR Aircraft Handled and Instantaneous Airborne Counts; FY 1981 - 2011, Office of Aviation Policy and Plans, June 1981

Reference 2 Computer Utilization at Several En Route Air Traffic Control Centers (A3d2.9 System), Jacques Press, ARD-140-1-81, December 1980

Reference 3 Computer Utilization at Several En Route Air Traffic Control Centers (A3d2.10 System), Jacques Press, ARD-140-8-81, June 1981

Reference 4 Traffic Loads and Computer Utilization Patterns at the Twenty En Route Air Traffic Control Centers, Jacques Press, ARD-140-8-81, June 1981

Reference 5 GENOT RWA 8/11, dated January 20, 1978

Paragraph 1024, System Saturation Warning Procedures, FACILITY OPERATION AND ADMINISTRATION, FAA Directive 7210.3E, August, 1979

APPENDIX — 3

ECONOMIC ANALYSIS OF INVESTMENT OPTIONS

TO REPLACE THE EN ROUTE CENTER COMPUTER SYSTEM

A QUANTATIVE ASSESSMENT OF BENEFITS AND COSTS

Foreword

This document presents an economic analysis of the various options identified in the Congressional Recommendations. The various cost benefit evaluations provided part of the information data base used in the numerous scenarios considered in the Administrator's review and evaluation of the Advanced Automation Program.

Using the information developed in the various evaluations of the specific options, it was possible to compare options, combinations of options and variations of options in assessing the more viable choices. Consequently, as each of the scenarios were scrutinized, it was possible for the Administrator to evaluate and choose the more desirable characteristics of the various options to formulate a specific course of action for the Advanced Automation Program. It should be noted that the selected approach does not represent any of the specific options evaluated and may be higher in cost since it has been postulated that two separate sets of parallel contracts will be used, with a longer competitive phase for the System contractors. One set of contracts will be for the Host hardware that will provide earlier increases in computer capacity, while the second set of contracts for the system will provide for early sector suite implementation to obtain productivity gains as the forerunner to the total system replacement.

EXECUTIVE SUMMARY

1.0 Background. Shortly after release of the Senate Appropriations Subcommittee's report, the FAA's Office of Systems Engineering Management began developing a benefit-cost model for use in evaluating all of the FAA's engineering and development (E&D) programs. At the outset, it was envisioned that the benefit-cost model under development would also be of use in analyzing various options for dealing with both near term enhancement and ultimate replacement of the current en route computer system.

Today, the model is fully implemented and has played a key role in the development of answers to the Subcommittee's inquiries regarding the near term, interim, and far term options.

1.1 Methodology. The methodology used in the benefit-cost model is straightforward. Input data is required in the form of time streams of costs and benefits. The model then aggregates the various costs and benefits for each option, discounts these aggregations, ratios the discounted aggregates, and then finally ranks the options according to their benefit-to-cost ratio and benefit-minus-cost difference.

1.2 Guidelines. The studies were conducted under the following guidelines:

(a) Sunk costs and benefits were not included.

(b) Costs and benefits were discounted at the OMB recommended rate of 10% per year compounded annually.

(c) Costs and benefits were measured in terms of the 1981 dollar's purchasing power.

(d) No inheritance or scrap values were included.

(e) The time span covered 30 years from CY-1982 through CY-2011.

The detailed study report Economic Analysis of Investment Options to Replace the En Route Center Computer System, A Quantitative Assessment of Benefits and Costs, is provided in Appendix 4. The following material represents an executive summary of the detailed study report.

2.0 Benefit/Cost Results of Near Term Options

2.1 Benefits

The benefits for the near term options represent reductions in cost to the users of the system as well as to the government.

The four benefit categories included were:

(a) reductions in fuel costs

(b) reductions in delay costs

(c) reductions in the controller work force

(d) reductions in the maintenance work force

A safety benefit was quantified separately in terms of reduced risk rather than in terms of monetary units. The translation of reduced risk into monetary gain is an almost impossible task from a statistical standpoint, given the outstanding safety record of the ATC system to date.

It is still too early in the program's evolution to develop meaningful reliability cost and benefits profiles, so that level of specificity has not been reached. Consequently, no monetary benefits or costs associated with safety and reliability were included in the analysis.

2.2 Costs

The costs include the development and implementation of a series of E&D programs all related to the performance of the en route function in the ATC system. These programs are therefore interrelated and definitely synergistic with respect to the en route function. Costs include the development as well as the implementation phases for each of these E&D programs.

The E&D program costs included are:

(a) Hardware and/or software for the various computer options

(b) Mode S Ground

(c) Mode S Avionics

(d) Other:

(1) Conflict Alert for VFR Intruders

(2) Conflict Resolution Advisory System

(3) En Route Metering

(4) Electronic Tabular Display Capability in Sector Suite Interface

(5) Mode S System Interface

(6) Central Weather System Interface

(7) Terminal Information Display System Interface

2.3 Results Obtained

The benefit-to-cost ratios and the benefit-minus-cost differences of the four near term options are shown in Table 1.

All of the near term options offer attractive benefit-to-cost ratios as well as significant benefit-to-cost differences. Assuming that these near term options are independent in a statistical sense, the differences in B/C and B-C are insignficant. The choice among near term options must thus be based on other considerations.

3.0 Benefit Cost Results of Far Term Options

FAA analysis indicates that en route computer hardware and software must be replaced and new controller sector suites installed if desired far term automation goals are to be met. Options 5-8 explore different far term approaches for these replacements and map out eventual extensions to achieve higher levels of en route automation.

3.1 Benefits

The benefit categories used in the analysis of the far term options are identical, and therefore directly comparable, to those used in the analysis of the near term options.

3.2 Costs

The cost categories used is the analysis of the far term options are likewise identical, and therefore directly comparable, to those used in the analysis of the near term options.

TABLE 1

DISCOUNTED SUMMARY

(billions of dollars - CY-81)

OPTION	TOTAL BENEFIT	TOTAL COST	B/C RATIO	B-C
2A Speed-up of 9020A	4.04	0.32	12.51	3.72
2B 9020 "A" to "D" Conversion	4.62	0.36	12.80	4.26
3A Functional Splitting-IOCE	3.86	0.41	9.35	3.45
3B Functional Splitting-Prime Channel DARC	3.75	0.34	10.99	3.41
4A Replacement with Interim Computer (HOST) Full Rehosting Activity	4.67	0.49	9.60	4.18
4B Replacement with Interim Computer (HOST), Accelerated Rehosting Activity	4.69	0.48	9.69	4.21

3.3 Results Obtained

The benefit-to-cost ratios and the benefit-minus-cost differences of the far term options are shown in Table 2. All of the far term options provide reasonably attractive benefit-to-cost ratios as well as significant benefit-to-cost differences.

Assuming that these far term options are independent in a statistical sense, the differences in the various values of B/C and B-C are insignificant. The choice among the far term options must therefore be based on other than economic considerations.

4.0 Comparison of Benefit-to-Cost Results of Near Term Option vs. the Far Term Options

Remembering that there are no statistically significant benefit-cost differences among the near term options and that there are no statistically significant benefit-cost differences among the far term options, the question arises as to whether there is a statistically significant benefit-cost difference between the near vs. the far term options. The benefits and costs of the near term options do differ statistically from those of the far term options.

What we find is that the benefit-cost-ratios of the far term options are significantly less than those of the near term options. However, (and this is most important) the benefit-minus-cost differences of the far term options are significantly greater than those of the near term options.

In essence, while the far term options cost more, they also return more, albeit at a somewhat lower rate of return.

TABLE 2

DISCOUNTED SUMMARY

(billions of dollars - CY-81)

	OPTION	TOTAL BENEFIT	TOTAL COST	B/C RATIO	B-C
5.	Interim Host followed by Full Replacement System	8.51	2.12	4.01	6.39
8A.	Replacement System built around Interim Host, distributed approach	8.70	2.11	4.13	6.59
8B.	Replacement System built around Interim Host, mainframe approach	8.70	2.14	4.06	6.56
6.	Multi-step Transition to Replacement System	8.57	1.99	4.30	6.58
7A.	Single Step Transition to Replacement System 5-3-2-1	8.61	2.10	4.10	6.51
7B.	Single Step Transition to Replacement System 3-1-1-1	8.84	2.02	4.38	6.82
7C.	Single Step Transition to Replacement System 5-2-1-1	8.84	2.08	4.25	6.76

TABLE OF CONTENTS

Economic Analysis of Investment Options to Replace the En Route Center Computer System

A Quantitative Assessment of Benefits and Costs

I. Introduction

A. The requirements for a computer replacement program.

B. Investment options considered

C. What is the proper role of benefit/cost analysis in assessing these options?

IA. The Requirements for a Computer Replacement Program.

A preliminary review of the past experience and the expectation of future events affecting the performance of the present 9020 computer configuration was conducted by the FAA.1/ It concluded that a need existed to consider a 9020 replacement system because of:

a) The anticipated growth in air traffic beyond the year 2000. At this writing, the events following the strike of the air traffic controllers have not only impeded the expectation of growth, but they have curtailed traffic activity significantly. These events are regarded as temporary, however, and the far term expectation is for the resumption of an increase in demand for service to levels previously forecast.

b) The high hardware and software maintenance costs for the present system. In addition, there is an expectation of a phase-out of the manufacturer's production of replacement parts for the current system. The future supply of parts can only be attained at a still greater increase in maintenance costs.

c). The growing need to add new functions to the computer system to support improvements in safety and productivity.

d). The need to reduce the consumption of aviation fuel.

e). The limitations in memory-core capacity of the current system which have resulted in operational delays at some centers on days of peak traffic activity. The consequences in economic penalties due to these delays and the number of centers that will experience them are expected to grow to unsatisfactory levels in the future.

f). The inherent reliability of the more advanced computer technology affords the opportunity to increase system reliability and to reduce system outages significantly.

g). The combination of increased levels of automation provided at a greater level of system reliability and at lower operational costs results in improvements in productivity and translates into the opportunity to save on controller staffing.

1/ "System Requirement Statement for Air Traffic Control Computer Replacement" draft memo; AAF-710, 1981

Each of the above items a) through g) represents a requirement to improve the current en route computer system, and each was assessed for its potential to provide either increases in dollar benefits or reductions in costs. The results of this assessment are summarized below in section II.

The categories of increased dollar benefits or cost reductions included in the assessment are:

1. Avoidance of operational delay costs due to the capacity limitations of the current system.
2. Reductions in utilization of fuel.
3. Increases in controller productivity, savings in staffing levels.
4. Reductions in maintenance costs.
5. Enhancements to safety, a reduction in system errors.

This last benefit category, the measurement of enhanced safety, serves to point up a feature of all benefits/costs analysis; a feature which is discussed in greater detail in Section II.2 of this Introduction: Some attributes of a proposed system's performance, and often the most important ones, are extremely difficult to quantify and, most particularly, in dollar terms. Assessments of improved performance in safety, for example, must of necessity be based in large measure on subjective and qualitative judgments. Fortunately, there are too few accidents for an analysis to be statistically confident about how improvements in safety might be related to a specific proposed program.

The assessment of benefits and costs included in this present analysis attempted to quantify some of the safety benefits that would accrue to a new computer system capable of reducing human errors. This assessment was made in the physical units of "reduced errors" and was not translated into dollars. Thus, the benefit/cost assessement--expressed as a ratio of dollar values--does not include the critically important category of safety. The results of a separate assessment of safety is shown in Table 3, of Section II.B. But this does not mean that the safety implications of all the investment options have been evaluated adequately. To repeat, measurement is difficult. A large measure of judgment is required to complement the numbers which are presented.

IB. Investment Options Considered 2/

The following investment options were considered in the benefit/cost assessment. Each option was evaluated for its ability to generate some measurable improvement in each of the five categories of benefits or cost reductions listed above.

2/ This summary was condensed from descriptions appearing in: "Draft Letter; Interim Response," from AOA-1 to Chairman, Subcommittee on Transportation and Appropriation, July 1981; Enclosure 5, para. 2-6.

The development work for most of these activities has been completed and implementation will be completed in 1981. This option will provide an increase or buy-back of approximately 30% in computer computation capacity at 9020A sites and 10% at 9020D sites. For the purpose of estimating benefits and costs this option was assumed to be already implemented and the dollar estimates shown for all other investment options are incremental or compared, to this "basic" option.

Option 1 - Base Option; Continue with the Present System, with some Capacity Modifications (The "do-nothing" option)

These actions include only those capacity modifications which have already been programmed for implementation and which use the current hardware and software system:

- Adding additional storage elements
- Offloading programs to the Input/Output Control Element (IOCE)
- Redesign of Program tables to make them more efficient
- Improved Data Recording procedures

Near Term Actions to Provide Additional Capacity.

Option 2 - Increase 9020 Capacity

This option includes hardware, software and precedural techniques which would enhance the capacity of the 9020 computer complex. Several strategies for meeting the general description for option 2 were analyzed, and the following specific strategies within this option were identified as being preferred.

2.2A. Replace the core memories of 9020A and 9020D with larger and faster state of the art semi-conductor memory. Convert 9020A processor to increase the instruction execution speed. The memory replacement is a prerequisite for the processor speedup.

2.2B. Replace 9020A's with 9020D's.

Option 3 - Partial Rehost of 9020 Software

This option considers the rehosting of some ATC software in larger and faster machines as well as the total rehosting of some major functions in new hardware systems.

3.3A. IOCE Replacement. Would replace the current input/output control element (IOCE) with a modern instruction-compatible machine, such as the IBM 4341. The greater capacity and speed of the new IOCE would allow offloading of significant parts of the software from the Central Computer Complex (9020) onto the new IOCE; thereby alleviating some of the 9020 capacity problems. This option could be implemented in 1985.

3.3B. Prime Channel DARC Presumes the implementation of enhanced Direct Access Radar Channel (DARC). The enhanced DARC is further modified with appropriate software and hardware changes to complete offloading of the radar data processing functions from the 9020 to the DARC system. This option will significantly increase the capacity of the 9020 system, as well as increase the reliability and availability of the ATC functions. This option could be implemented in 1986.

Interim Actions to Eliminate Future Capacity Problems

Provide Platform for Future Automation

Option 4 - Replace 9020 Hardware Keep Software

4.4A. Full Rehosting Activity. This option replaces the current computers and peripherals with a duplex configuration main frame computers capable of executing the existing software (one active; one standby) and new peripherals. The design and recoding of a limited amount of software will be required to efficiently rehost the current applications software. The new computers, while imposing a 25% overhead for rehosting, have at least four times the computing power of a 9020D and therefore, would alleviate any potential capacity problem while a replacement system is implemented. The structure of the 9020 software, which would still be used on the main frame, would limit functional improvements and would not allow for enhanced levels of automation. This option could be implemented in 1986.

4.4B. Accelerated Rehosting Activity. A variant of this option would keep the current 9020 peripherals and would use a more "brute force" approach to host the 9020 software on a state-of-the-art processor capable of executing the existing software. The inefficiency for hosting would go up to 50%. This approach has been proposed by the Amdahl Corporation. This option could be implemented in 1985.

Implement Interim Platform to Full Automation

Option 5 - Interim Host Followed by an Advanced Computer System

Option 5 utilizes an interim system (option 4) as a necessary first phase, but full computer replacement (hardware and software) is retained as the long range objective. As such, parallel programs are proposed in order to develop and implement this option. The first phase replaces the current system with a computer capable of executing the retained existing software. The second phase which is initiated concurrently, develops a new computer system and appropriate software capable of meeting all far term requirements. The interim system would be replaced upon introduction of the full capability system. Implementation of the first phase interin host hardware replacement could be in 1986. Phase 2, the Automated Computer System could be implemented in 1993, but the Advanced Automation would not be fully operational until 1994 or 1995.

Option 8 - Replacement System Built Around Interim Host

Option 8 is similar to option 5 in that it uses option 4 as an interim building block in reaching full automated levels in the future. The initial phase will replace the current hardware with hardware capable of executing the existing software and it will rehost the current software.

However, where Option 5 provides for a complete parallel development of the replacement system, this option proposes successive upgrades of the interim system by a step replacement of software and hardware until a full capability system is achieved. Alternative techniques for modifying the hardware under this option were examined.

Option 8a, Distributed Approach. It is assumed that the Replacement System hardware will be kept, and that the needed hardware enhancements for the Advanced Computer System will be gained by adding additional processors outboard of the mainframe computer.

Option 8b, Mainframe Approach. In this sub-option, the hardware enhancement for the Advanced Computer System will be achieved by substituting a larger system (prehaps bus oriented) of the same family (presumably incorporating the latest technology) for the Replacement System hardware.

Option 6 - Multi-Step Transition to Replacement System.

Option 6 is a three-phase evolution of the current computer system. The initial phase augments the current computer system with new hardware and implements new software for the Radar Data Processing (RDP) and display functions. Some new functions are included. The second phase provides additional hardware augmentation and replaces the remaining software related to Flight Data Processing (FDP). This second software module also adds new functions related to flight data processing. The final phase adds the hardware and software elements necessary to achieve an increased level of automation in the air traffic control system. This option will be implemented to full automated capability in 1993.

Option 7 - Single Step Transition to Replacement System

Option 7 is the most direct approach to obtaining a replacement system with the capability both to solve current problems and leading to the desired full capability system. The first phase of this option replaces the current hardware and software with new hardware and software, and adds 7 new functional improvements. The hardware and software is initially designed to readily accommodate increased levels of automation through modular additions of hardware and software. The second phase implements these modules in order to provide the desired level of automation. Several strategies within this option were analyzed. They differ only in the procurement process used to acquire the option. The numbers shown in the description offered for the individual procurement strategies refer to the number of contractors competing through the successive phases of the acquisition process (reference OMB Aquisition Process Circular, A-109).

7.7A. Contractors: 5-3-2-1
7.7B. Contractors: 3-1-1-1
7.7C. Contractors: 5-2-1-1

Implementation for all option 7 modifications could be achieved for the full Advanced Automation in 1992.

IC. The Role of Benefit/Cost Analysis

A logical rationale to follow in making an economic decision regarding an investment option is to choose to exercise the option if the quantified estimates of dollar benefits exceed the dollar estimates of costs resulting from its implementation. While this, in theory, is a simple investment rule to follow, it may, in practice, be exceedingly difficult to obtain "quantified" and "dollar estimates" of benefits and costs which are directly attributable to the proposed program. In fact, it is very likely that it may not be possible to measure the improvement made by this program in any of its important performance categories; but, most particularly, in the critically important category of Safety. The tendency, then, is to regard some other attribute of performance as being more important merely because a method can be devised for estimating it. The difficulty in being able to quantify an improvement resulting from a proposed program is then compounded by the need to assign appropriate dollar values to any attribute of improved performance we may have succeeded in measuring. And, it is important to remember that both the quantifying of the extent of the improvement, measured in physical units, and the dollar values associated with the improvement must be estimated *for a proposed program operating in a future environment; for which no* data base of experience exists. Thus, all measurements concerning the potential performance of a proposed program must rely on some fundamental assumptions concerning the future world. Since these assumptions can never be proven in the present world, analyses which are based on them are always subject to challenge.

The best that an analysis team can do is to indicate the performance attributes it has succeeded in measuring as well as those it has not succeeded in measuring, and to state explicitly the assumptions included in the dollar estimates that are provided. In addition, the analysts have the responsibility to make reasonable assumptions concerning the future world; either based on a realistic assessment of future events, or employing the concept of a "worse case" analogue. An investment alternative which is evaluated as an economic choice under a set of "worse case" or conservative assumptions can only have this verdict confirmed to a greater degree when evaluated under less stringent circumstances.

The analysis presented in this section attempts to adhere to the recommendation that it is necessary to state all of the assumptions used to quantify the dollar benefits and costs explicitly, and to employ them in a conservative manner. But, due to the limitations inherent in the methods of analyses which it employs--by definition, only those attributes which are measurable can be quantified and included in the analysis even though they are not necessarily the most important ones--it must be emphasized that an analysis of benefits and costs cannot be the sole basis for making an investment decision. The results of these analyses must be tempered with independent and informed judgments, albeit subjective ones, of those future events in a changing world that are likely to affect the choice of an investment option. The results should be interpreted as a single, although essential, datum point in the matrix of information and uncertainty that surrounds an investment decision.

II. Summary Presentation of Study Results

The dollar amounts of benefits and costs associated with each of the investment options 2A, 2B, 3A, 3B; 4A, 4B; 5, 8A, 8B; 6, 7A, 7B, 7C are shown in Table 1. They are grouped according to the following classification: The first four options are those which provide for near term improvements to eliminate current capacity problems. The next five provide an interim solution which utilizes Option 4 to prevent any future far term capacity problems and which have the capability to build upon this option to eventually reach full automation via options 5, 8A and 8B. The final four options involve a direct replacement of the current system with a new system able to meet the goal of providing fully automated service.

The dollar amounts in Table 1 are non-discounted, 1981 dollars and provide a graphic example of the dollar variations in the various options. Table 1A provides the same information with the values discounted at a rate of 0.10 to the present. It can be noticed that the discounting process significantly reduces the net benefits achieved by the far term options (by a factor of 7) yet the ratio of benefits to costs remains relatively unaffected by this process.

In compiling the dollar benefits shown in Tables 1 and 1A, none were estimated to accrue until the implementation of an investment option was considered to be fully completed. A brief description of these options has already been provided in section I.B above.

The study's evaluation of dollar benefits and costs is intended to show how economic comparisons can aid in selecting a preferred investment option from among various proposed alternatives. A "first cut" selection of 13 options was compared to a "basic" option which proposed to make modest modifications only to the current system. It is essential that this group of options be examined under a comparable set of assumptions and conditions. It is expected and even desired that this assessment would suggest other investment options or combinations of options.

Those options which appear to be advantageous after a "first cut" analysis were then subjected to further examination using the latest available information. But, for completeness and comparability sake, this means that the entire list of options including the less promising ones should be examined again under the same but revised set of conditions; modified in the same way for all. This was not done, however. Only those options which survived a previous round of analysis were compared under the new set of assumptions.

All options were subjected to a continuing review by task group 2: the group responsible for making the operational and technical evaluations of all investments alternatives. For example, by examining the original list of options presented below it was apparent that option 7--a one-time single replacement option--was at an economic disadvantage compared to those which accomplished the replacement in steps; options 5 and 8. These latter options were able to eliminate the near term constraints imposed by a lack of computer capacity in a more timely manner prior to the eventual attainment of full automation. Thus, the analysis suggested that a combination of options, near term plus far term (e.g. options 2B plus 7C) would be more attractive economically.

For this reason, this section of the study which is intended to illustrate how quantified estimates of benefits and costs can be used to guide investment decisions at any level of analysis may differ in some details from the latest list of options, implementation schedules or cost estimates currently being used by task group 2.

The more recent technical information and operational descriptions are available from the summary reports issued by this group (see Supplementary Report E).

Table 1. Summary of Dollar Benefits and Costs Categorized by Investment Option (in billions of 1981 dollars)

	I	II	III	IV	V	VI
	Option	Total $ Benefits	Total $ Cost	Net Benefits ($B-$C)	Ratio (B/C)	Safety Benefits Reduced System Errors(SE) (in SE units)
Near Term to prevent current capacity problems.	2A	$19.26	1.53	17.73	12.59	3000
	2B	25.44	1.98	23.46	12.80	3000
	3A	18.16	1.93	[illegible]	9.41	3000
	3B	17.13	1.55	[illegible]	11.05	3000
			PHASE I - Platform			
Interim to prevent long-run capacity problems; provide potential for automation	4A	26.44	2.77	23.67	9.54	3000
	4B	26.44	2.71	23.73	9.76	3000
			PHASE II Fully-Automated System			
	5	59.96	14.94	45.02	4.01	8000
	8A	60.41	14.65	45.76	4.12	9000
	8B	60.54	14.89	45.65	4.07	9000
Far Term						
			Single Replacement			
	6	59.33	13.76	45.55	4.31	8000
	7A	60.27	14.70	45.57	4.10	8000
	7B	59.99	13.71	46.28	4.38	9000
	7C	60.44	14.22	46.22	4.25	9000

Table 1A. Summary of Dollar Benefits and Costs Categorized by Investment Option (in billions of 1981 dollars, discounted at rate of 0.10 to the present)

	I	II	III	IV	V	VI
	Option	Total $ Benefits	Total $ Costs	Net Benefits ($B-$C)	Ratio (B/C)	Safety Benefits Reduced System Errors(SE) (in SE units)
Near Term to prevent current capacity problems.	2A	$4.04	0.32	3.72	12.51	3000
	2B	4.62	0.36	4.26	12.80	3000
	3A	3.86	0.41	3.45	9.35	3000
	3B	3.75	0.34	3.41	10.98	3000
PHASE I - Platform						
Interim to prevent long-run capacity problems; provide potential for automation	4A	4.67	0.49	4.18	9.60	3000
	4B	4.69	0.48	4.21	9.69	3000
PHASE II Fully-Automated System						
	5	8.51	2.12	6.39	4.01	8000
	8A	8.70	2.11	6.59	4.13	9000
	8B	8.70	2.14	6.56	4.06	9000
Far Term						
Single Replacement						
	6	8.57	1.99	6.58	4.30	8000
	7A	8.61	2.10	6.51	4.10	8000
	7B	8.84	2.02	6.82	4.38	9000
	7C	8.84	2.08	6.76	4.25	9000

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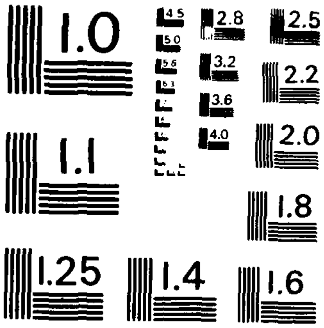


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

It would be appropriate at this point to add a note about the interpretation to be placed on the results shown in Table 1.

The rule which recommends that an option be implemented in place of its next best alternative, if it adds any dollar amount more to benefits than it does to costs, is based in simple logic. It states that it is possible to achieve ever increasing levels of performance (--to maximize profits in the case of the individual firm, or to obtain the greatest social benefits in the case of a government institution--) as long as each successive step provides some positive increment. Being based in logic the road toward achievement of the highest goal obtainable has no reverence for memory. Thus, there is no requirement that each and every successive step add more to the tally of net benefits than the last one. In fact, any economic decision under these circumstances (referred to in economic theory as one of "increasing returns to scale") is trivial; the proper decision is to avail oneself of the increasing rate of return by always choosing to invest. It is only in the area of "diminishing returns"--when each successive investment adds a lower total of net benefits than the last one--that an economic decision is required. Economics, after all, is involved with the making of decisions when resources are scarce and must be allocated to their most productive use; that is, all economic decisions are made when the conditions of "diminishing returns to scale" prevail.

This discussion permits us to interpret the results shown in Tables 1 and 1A in an appropriate light. For example, a proper economic decision is not made by selecting the option with the highest total of net benefits shown in column IV, or by the highest ratio of benefits to costs shown in column V (i.e., the "near term" improvement option 2B). A "near term" choice is not preferred over those investment options shown as "full replacement" even though the ratio of benefits to cost for this latter option is 4 to 1; a much lower ratio than the 12 to 1 which results from a choice to invest in "near term" improvements:

It is essential to remember that these alternative investment options attain different objectives or goals. Each option in Tables 1 and 1A is compared to the "base" option. The base for comparison is the system that will be in place by the year 1981. The present system is being augmented by a program that will achieve a 30 percent "buy-back" of computer capacity. Table 1A indicates that the option to invest in near term improvements beyond those contained in the "base" option is a good one economically; by a ratio of about 12 to 1. This comparison also indicates that if an investor were interested only in the objective of providing near term improvements by eliminating the costly bottlenecks in the current system, that option 2B should, possibly, be preferred. The benefit to cost ratio is improved from the best to the worst option in this group, by some 37 percent (12.80 divided by 9.35); an indicative if not totally convincing difference.

The results also indicate that if the objective of the investment analysis were strictly limited to a choice of "near term" improvements, that there would be little quantifiable justification for preferring option 2B to option 2A; a ratio of 12.80 is not much different from 12.51. But, there is an additional, and even more important, indication for investment implicit in Table 1.

In the same way that the calculations of benefits and costs provide a basis for selecting options capable of meeting a given objective level, they provide an economic basis for selecting the next higher objective. Note in Table 1A that a potential increase in benefits of some $4 to $5 billion can be obtained by implementing the far term, full replacement, options instead of the near term, capacity improvement, options. (Compare the $8.5 to $8.8 billion in benefits from options 6 and 7 to the $3.8 to $4.6 billion in benefits available from options 2 and 3. The additional costs to implement the far term options in place of the near term ones are much less than the $4-5 billion in benefits; the difference in cost is, in fact, only some $1.8 billion (Compare the $2 billion in total costs shown in Table 1A for options 6 and 7 with the $0.3 billion shown for options 2 and 3). Based on these quantified dollar estimates it is clear that a decision to implement the "full replacement" options is much preferred economically to the alternative choice of the "near term" options. Net benefits (benefits less costs) of $2 billion would result from such a decision (see column IV, Table 1A). This translates into an implicit ratio (not shown in Table 1A) in excess of 2 to 1: $4-5 billion in additional benefits at an additional cost of less than $2 billion

It is interesting to note that while the signal is clear to invest in any of the investment options capable of providing a fully automated ATC system, the implicit incremental benefit to cost ratio is "only" in excess of 2 to 1 This is lower than any of the other ratios shown in Table 1A. The reason can be found in the simple rule of logic cited previously: economic decisions have no reverence for memory. Each decision is a new one in which "bygones are considered to be bygones." Thus, it is irrelevant that a previous decision, for example, to implement the "base option" (30 percent buy-back) in the year 1981 may have shown a benefit to cost ratio of, say, 33 to 1 when compared to today's unaugumented system. This historical ratio tells us nothing, however, about whether a subsequent decision should be implemented to achieve still higher objectives; for example: whether "near term" improvements are preferred to the "base" option.

The study's calculated benefit to cost ratios shown in Table 1A indicate that the "near term" option is, indeed, preferred over the "base" option; the range is from 9.35 to 12.80 depending on the individual option selected. These ratios also indicate, however, that the full replacement options 5 through 8 are preferred both to the "base" option (by a ratio of 4 to 1) and to the "near term" improvement option (by an implicit ratio greater than 2 to 1). To repeat, the fact that the benefit to cost ratio decreases as the attempt is made to reach higher and still higher objectives for ATC service should not be taken as an indication that there is no economic justification for reaching for these objectives. To the contrary, Table 1A provides a sufficient, quantifiable, justification for a decision to invest in an en route computer facility capable of providing fully automated services.

The justification for choosing a proposed program must be an incremental one; the comparison of benefits and costs are to be made to the next best alternative and not to all the investment alternatives which preceded it. The observation that the benefit to cost ratio is decreasing for successive decisions is not relevant to the decision at hand. The only condition for economic justification is that the ratio of benefits to costs for the new decision exceed 1.0 to 10. The successive reductions in calculated ratios merely reflect the fact that economic choices are not being made in an arena of unlimited resources ("increasing returns to scale") but, rather, reflect the more typical and representative condition of making economic decisions in a world of scarce resources (where returns "diminish to scale").

Summary Conclusions

Table 1A reveals that there is ample economic justification for a "near term" program to improve the "basic" system, if the objectives of the ATC system are limited to those attainable by the current system. Options 2A and 2B appear to be preferred for meeting these limited objectives.

These near term options are able to avoid the costly problem of operational delays which result from the use of the basic option. They are able to postpone, but not eliminate, the problem of future operational delays due to constraints in the current system's computer capacity. But, even these near term benefits are probably being overstated for the following reasons:

To begin with, the costs for spare parts for the current computer equipment incorporated into the near term options do not include the likely possibility that these parts will be more difficult to obtain, even at premium prices, once the production line of the manufacturer of the present computer equipment is shut down. Thus, the near term options may be feasible alternatives only until the late 1980's, or thereabouts; a period earlier than the 1990's when operational delay problems caused by lack of computer capacity are anticipated to reoccur.

In addition, the estimates of the utilization of computer capacity were based on current levels of functional service. However, all investment options considered in the study were designated to include a future package of seven automated functions listed below in Section IV, C. The calculations of computer utilization for the near term options are likely, therefore, to be seriously underestimated.

Despite the study's optimistic conclusion regarding the feasibility of implementing the near term options as the preferred investment decision to meet the limited objectives of avoiding computer capacity problems, this conclusion is made obsolete by further analyses which reveal that there is an economic justification for investing in options capable of attaining still higher ATC objectives; to a fully automated system. The far term options are preferred economically over the near term ones.

Based on the benefit and cost calculations performed in evaluating these options (5 through 8), there is no quantifiable evidence to support the selection of a single, preferred, option from within this far term group.

II.A. THE STUDY METHODOLOGY

Each of the investment options--near term, interim and full replacement--described in section I.B was compared, alternatively, with the option of staying with the 'basic' system. The base of comparison against which all future investment options were measured, is the system currently in place (September 1981) but augmented with a program that will provide a 30% buy-back of computer capacity. The implementation of this program to augment core memory is scheduled for completion by the end of the current year.

The program life of all investment options was estimated to be 30 years. The planning horizon for comparing options must be sufficiently long so that new and major investments which may involve extensive replacements of equipment, have a period in which to recoup the costs of the investment. Planning horizons which extend beyond 30 years exceed our forecasting capabilities. The estimates of flight activity forecast to occur during the study's planning horizon, the years from 1982 to 2011, were supplied by official FAA sources: Office of Aviation Plans and Policy (APO-1).

The rate at which the implementation of each of the proposed investment options was estimated to take place--the number of installations, the type of equipment being replaced or modified, and the schedule for completion--was considered to be an integral part of the proposal itself. No general schedule of implementation fits all options, but each was made to satisfy explicity defined objectives at precisely designated intervals. The assumption that all investment options will meet their goals in a timely fashion is an extremely critical one. The inability of a given option to meet a performance objective at the time designated, seriously compromises the study's results because the study's method for differentiating between alternative investment options depends primarily on the timing of the receipt of benefits, and the incurring of costs. The dollar impact of this difference in timing is heightened by the study's imposition of a procedure prescribed by the Office of Management and Budget (OMB)3/ to discount all future dollar values by a factor of 0.10.

To calculate the discounted dollar value, it is necessary to divide the undiscounted dollars totals occurring in some year, which is "t" years from now, by the factor: $(1+r)^t$ where r is the prescribed discount rate of 0.10. All discounted values presented in this study were included at this prescribed rate.

Those investment options requiring major replacements of equipment which will be available at a later date, will have their estimates of dollar benefits cited in "low-power" (highly discounted) dollars; On the other hand their costs which occur earlier will be expressed in "high-power" (low discounted) dollars. As an example of the impact of 'discounting,' it should be noted that the dollar benefits estimated to accrue to some investment during the year 2011, the last year of the planning horizon, will be included in the study at a value of approximately five cents on the dollar.

3/ Office of Management and Budget; Circular A-94

The study's method assumed that the dollar benefits from any future investment option did not begin to accrue until the implementation phase of the option was fully completed. This is a conservative assumption which mitigates against those options with longer implementation schedules, since a larger portion of their benefits are being calculated in "low-power" dollars.

Since the schedules for implementation are critical to the dollar values which were estimated, an indication of the sensitivity of the study's results to these schedules can be obtained by evaluating the investment options in "undiscounted" dollars. For this reason, the actual (undiscounted) dollar amounts accruing for each year of the 30 year planning period are also reported in the study for each option. A comparison of the aggregate total of "discounted" versus "undiscounted" dollars for each option, will indicate the effect that implementation schedules have on the study's conclusions.

This comparison is shown in Table 1B in which the totals of discounted net benefits for each option have been transferred from Table 1A and placed alongside of dollar values which have not been discounted from Table 1.

The differential effect of discounting, which favors the near term over the long-run investment options, can be noted by the 5 to 1 reduction in net benefits for the early options, and the 7 to 1 reduction for the later ones.

The impact of inflation on the study's results has been eliminated--future inflation rates will not affect the results--by the citing of all estimates in the constant-value purchasing power of the 1981 dollar. In those cases where dollar amounts of estimates may have been quoted in dollar values for years prior to 1981, the translation to 1981 dollars was made by using the Producer's Price Index (PPI). If the study found it necessary to translate a dollar amount quoted for some future period into an equivalent total expressed in 1981 dollars, a forecast of a ten percent rate of inflation was used.

TABLE 1B

SUMMARY OF NET BENEFITS (Benefits less Costs)
Categorized by Investment Option
Discounted at 0.10 vs Undiscounted
(in billions of 1981 dollars)

Option	$Net Benefits Discounted Total	$Net Benefits Undiscounted Total
2A	$3.72	$17.73
2B	4.26	23.46
3A	3.45	16.23
3B	3.41	15.58
4A	4.18	23.67
4B	4.21	23.73
5	6.39	45.02
8A	6.59	45.76
8B	6.56	45.65
6	6.58	45.55
7A	6.51	45.57
7B	6.82	46.28
7C	6.76	46.22

II.B. THE MEASUREMENT OF ATC PERFORMANCE

1. The Factors That Could Be Quantified in Dollar Terms

The study attempted to measure the improvements in benefits that would occur as a result of implementing each investment option instead of continuing with the basic system in place. This means that all benefit dollars which are shown are incremental; they represent increases in ATC performance over and above what would have been achieved with the incumbent system.

ATC performance can be measured as a three dimensional entity: 1) safety, 2) time-in-system and 3) number of aircraft serviced. These entities are not separate and independent but interact to provide a multi-facted level of performance. The impact of a system outage or a reduction in the capacity of a facility can not be measured by a single facet of performance. Reduced capacity for example, doesn't result merely in increased delays, but it will also impact, interactively, on safety and the numbers of aircraft that can be serviced. Thus, it does not make sense to conclude that a system is performing better based solely on measured improvements in the time spent in the system (i.e., delays are reduced) if there is no assurance that the other dimensions of performance, in particular, safety, were not compromised in order to achieve this performance.

In the same way, improvements in safety achieved by limiting the number of aircraft serviced are not necessarily indicative of superior overall performance. Surely, they are less desirable than a performance in which the same safety improvements are achieved without placing a limit on traffic activity. And, finally, if one were foolhardy enough to ignore all considerations of safety, the recommendation would follow that the way to improve the performance dimension of "time-in-system" would be to allow an unrestricted free-for-all, flow of traffic between airports.

It is clear, therefore, that in attempting to measure improvements for a multi-dimensional variable like ATC performance, it is necessary to measure all dimensions simultaneously. For many types of analyses, it may be possible to consider how overall performance might be rated based upon a "mixed" result--some facets of performance are up, some are down--by using a set of weighting factors in order to combine the disparate results into a composite measure of performance. But, in dealing with problems in air traffic control, the implicit weighting factor for safety is so dominant that it limits our ability to deal with "mixed" results; and, in particular, with "mixed" results in which safety is involved. Any claim of an improvement in performance which compromises safety is considered to be invalid, no matter how large the improvement claimed for the other dimensions of performance: time-in-system and numbers of aircraft serviced.

In effect, the analysis presented in this study is predicated on the assumption that no compromise in safety occurs, and that quantified claims for dollar benefits resulting from improved performance can be based on estimates made in the other dimensions of performance. More specifically, the study's methodology employed the analytical stratagem of using the third dimension of performance--numbers of aircraft serviced--as a system requirement. Forecasts of traffic activity levels were based on official FAA estimates of the future demand for service by the aviation user. The study assumed that the ATC system would service this forecast demand for service with its customary high level of safety.

For those ATC facilities for which the forecast of demand exceeded the facility's capacity to accommodate it, the study estimated that there would be a deterioration in the performance dimension of "time spent in the ATC system;" operational delays will increase. Proposed programs for which no deterioration in delays was estimated to take place despite the increase in traffic, and which did not compromise safety, were represented in the study as having a dollar benefit which derived from the avoidance of the disbenefits or costs due to those operational delays which the study estimated would have occurred if the programs were not implemented. All program proposals or investments options were compared, alternatively, to the basic option of continuing to operate the current system with minor modifications.

Dollar estimates of benefits based on improved performance must be compared with the dollar costs needed to attain these benefits in order to make a rational investment decision. A decision to invest is rational if the net benefits (benefits less costs) for a program exceed zero. The estimates for costs may, for convenience sake, be looked upon as a fourth or negative dimension of performance. The arithmetic used to estimate net benefits is not affected by an arbitrary choice which defines a "savings in costs" as a program "benefit". Such a choice conforms to intuitive logic and yields the identical guideline for investment as one which strictly separates improvements in physical performance (benefits) from expenditures of resources (costs).

For this reason, the table of benefit categories shown below includes items which, in a strict analytical sense, are usually included as cost categories: 1) savings in controllers staffing levels due to increased productivity, 2) reductions in the costs for fuel, 3) decreases in maintenance costs. Note that negative increments to costs ("reductions", "decreases", etc.) are represented as benefits. Also shown on the benefits side of the ledger are the more typical items which reflect improvements in the performance categories of safety and time-in-system (delays). But, even here, the dollar benefits due to reduce delays were measured in the avoidance of the increased costs of operating delayed aircraft.

The cost categories for the ground system equipment and staff required for each investment option include the traditional life cycle costs of: 1) engineering development, 2) investment in equipment, spares and training, 3) operating and maintenance, exclusive of those incremental savings in costs which have been transferred to the benefits side of the ledger.

It is important that an accounting of dollar benefits and costs avoid the problem of "double counting". Analyses involving multi-dimensional levels of performance are vulnerable to errors of this sort. It is incorrect to document an improvement resulting from a single program change and then to present this same improvement in its many dimensions of performance. For example, for a given standard of safety and with no attendant increases in delay, it is permissable to estimate the improvement in performance for an ATC system by the increase in numbers of aircraft handled. Or, the analyst might choose to document how delays might be reduced (or, <u>alternatively</u>, safety might be increased) with the same program servicing a given level of traffic activity. But, it is essential that the analyst not double or triple count the same program improvement.

Table 2, indicates that the various investment options considered in the study have been estimated to offer improved performance in both the delay and safety dimensions of performance. But, the study has attempted to establish that the dollar values shown are independent and are not the result of double counting. For example, the argument for increased safety resulting from advanced levels of automation presented in attachment B is largely unquantified. There is no danger of a "double counting" of dollar benefits here. However, a benefit has been quantified for improved safety for systems employing advanced levels of automation. These benefits were estimated to result from a significant reduction in those system errors related to human causes. These benefits which were estimated in units of reduced system errors and not dollars, are exclusive of those claimed for "decreased delays". The dollar benefits for reduced delays were estimated in the study to result from the avoidance of capacity limitations imposed by the current computer system, and were not estimated to result from the implementation of advanced levels of automation.

To repeat, the delay benefits shown in Table 2 do not derive from the implementation of advanced levels of automation. They have been estimated to accrue to those investment options--near term as well as those designed for full replacement with advanced computer equipment--which are able to avoid the costly delays associated with having insufficient computer capacity to accommodate the demand for service forecast for the future.

Table 2. Dollar Benefits, By Investment Option: 1982-2011
(In Billions of 1981 Dollars, Discounted To The Present)

	Options												
Benefit Categories	2A	2B	3A	3B	4A	4B	5	8A	8B	6	7A	7B	7C
Increase System Safety (Not Quantified in Dollars)	--	(See Table 3)		--	--	--	--	--	--	--	--	--	--
Avoid Computer-Capacity Induced Delays	$1.20	1.79	1.02	0.91	1.80	1.80	1.80	1.80	1.80	1.68	1.73	1.75	1.75
Increase Controller Productivity *(Potential Cost Savings)	0.71	0.71	0.71	0.71	0.71	0.71	1.86	1.98	1.98	1.98	1.98	1.98	1.98
Increase Fuel Efficiency *(Potential Cost Savings)	2.13	2.13	2.13	2.13	2.13	2.13	4.77	4.85	4.85	4.85	4.85	5.05	5.05
Decrease Maintenance Costs *(Potential Cost Savings)	0.00	0.00	0.00	0.00	0.04	0.05	0.07	0.07	0.07	0.05	0.06	0.06	0.06
TOTAL DOLLAR BENEFITS	4.04	4.62	3.86	3.75	4.68	4.69	8.51	8.70	8.70	8.57	8.61	8.84	8.84

*(Cost Savings Included As A System Benefit)

2. Factors Not Quantified In Dollar Terms; Safety

In general, a conclusion concerning what was not quantified is an easy one; these factors important to the choice of an investment option and which have not been quantified, remain in the unquantified category. The important question for the analysis is to decide whether a consideration of this category of unquantified factors will change the study's conclusions or recommendations. The indications are, however, that a consideration of these technical and operational factors for which no acceptable method for measuring could be found, would only serve to reaffirm the conclusions of the benefit/cost analysis that was conducted.

Based upon those factors that could be quantified, the study concluded that the longer term computer replacement options leading to fully automated enroute service by the end of the decade represented superior investment decisions. The study's inability to recommend a spec ic investment option within the longer run full replacement group investment options -- reliance must be placed instead on other chnical and operational factors -- is surely consistent with the tautol ical view that the unquantified factors are important.

The most significant category of factors not included in dollar erms is safety; the primary objective of the ATC system. However, the study's recommendation which supports the long-run option is only reinforced by a consideration of the safety benefits available to a fully automated system of en route traffic control. From Table 3, it can be noted that the fully automated system provides the potential for reducing the forecast number of system errors by more than a factor of two, over the reduction available with near term improvements.

A partial listing of functional improvements made available by automation is shown below: 4/

1. Reduced or rationalized (more predictable, better organized) controller workload.
2. Better organized and more predictable traffic flows.
3. Faster, more accurate response to conflict.
4. Expanded alerting capabilities.
5. Improved inputs to pilot/controller.
6. Reduced communications errors.
7. Improved interface between controllers.

4/ This discussion excerpted from a working paper: MITRE Corporation "Automated Functional Improvements To The Current NAS System - Safety Benefits" August 5, 1981. Appended as Attachment A.

8. Increased automation system coverage.

9. Improved reliability and system backup.

The above safety related improvements are directed toward reducing system errors and accidents. But, fortunately, the number of midair collisions or other accidents resulting from system errors are few. There is, therefore, little experience for assessing the number of accidents or collisions that could be avoided with each of the improvement items listed. Their contribution to improved safety is more appropriately measured in reduced probabilities of risk. If there were some way to estimate this risk at some absolute probability level that was capable of being insured against, an assignment of dollar benefits due to improvements in safety could be made by measuring the reduction in insurance premiums available with each functional improvement. Such a method for quantifying the dollar value of safety benefits has not been developed to any acceptable degree, nor are we certain that the monetary assessment of losses likely to be incurred by insurance companies represents the true loss to society resulting from an aircraft accident.

However, the study devised a method for quantifying benefits from improved safety, based upon an estimated reduction in the numbers of system errors forecast, even though no dollar amounts were calculated for this reduction.

In the past several years, a number of studies of system error causes and prevention have been undertaken by the FAA. These studies have concluded that the cause of system errors is a complex amalgam of human errors, operating practices, equipment and communications.

System errors are presently reported at a rate of about 500 per year, with slightly over one half occurring in en route control. Analyses have indicated that over ninety percent of controllers' system errors are human errors, based in hardware or software failures. Thus, the major attention in system error reduction has been directed to aiding and improving the human element in ATC.

There is no accepted estimate of the rate of unreported errors. However, the annual rate of reported errors continues to grow. If the risk of a midair accident were considered to follow the model of gas molecules moving at random in uncontrolled airspace, the expectation would be that the risk of a collision would grow as the square of the number of aircraft within a given volume of airspace that were potential candidates for such a collision. But, historical data observed over long periods of time, plus data made available by dynamic simulations of the ATC system under controlled conditions, indicate that the risk of a collision under actual flying conditions appears to be proportional to the number of aircraft contained within a given volume of airspace; not the square.

The number of system errors was forecast to increase in proportion to future flight activity. The pattern observed in the past was estimated to continue to hold for the future. An analysis was made of each investment option's ability to reduce the number of system errors forecast. Those options which provide for fully automated levels of service were estimated to have the largest reduction due to the ability to virtually eliminate those errors created by human causes.
A table depicting the number of system errors forecast to be reduced by each of the investment options considered by the study is shown in Table 3. To repeat, the numbers shown are in units of "numbers of system errors reduced", not dollars.

Table 3. Reduction In Number of System Errors Forecast For Period 1981-2011, By Investment Option (Total Number of Errors Forecast = 11,000)

Investment Option	Total Number Reduced By
2A	3,000
2B	3,000
3A	3,000
3B	3,000
4A	3,000
4B	3,000
5	8,000
8A	9,000
8B	9,000
6	8,000
7A	8,000
7B	9,000
7C	9,000

III. Details of Study: Dollar Benefit Categories

A. Avoid Computer Capacity-Induced Delays
B. Increase Controller Productivity
C. Increase Fuel Efficiency
D. Decrease Maintenance Costs

III.A. Avoid Delays Caused By Computer-Capacity Limitations

In this section, an assessment was made of the operational delays to aircraft that would occur as a result of the level of traffic activity forecast for the 30-year period from 1981 to 2011 and the inability of the current system to service this forecast due to constraints in computer capacity. The dollar consequences of constraints to the current system and its inability to service future demand were estimated in the separate categories of: 1) inability to provide such ancillary or support functions as simulation training, data analysis, etc., during hours of peak activity, 2) the airborne delays incurred as a result of traffic management policies invoked when traffic activity approaches near-capacity (80%) levels, 3) the delays incurred on the ground by aircraft waiting to depart from local airport as a result of traffic activity reaching the (100%) capacity level, and 4) the elimination of the constraint due to system outages or failures resulting from equipment designed to past levels of computer technology instead of the inherently more reliable equipment of today.

The dollar amounts of dollar benefits calculated for the avoidance of operational delays in each of the above categories is shown in Table 4 for each investment option included in the study:

The dollar benefits shown for "support functions" were based on estimates of the costs necessary to obtain new equipment independent of the current computer complex that could provide the capability for "simulation training;" one of the support functions that must be deleted when traffic levels approach the limits of the computer's capacity.

The benefits for avoiding "airborne delays" shown in Table 4 were based on forecasts of "operational delay days" provided by an analysis team from FAA's Research and Development Service (ARD-130). Statistical correlation techniques were used to develop estimates of computer capacity utilization as a function of the level of traffic activity serviced. Estimates of future memory core utilization were generated from forecasts of future activity. On those days when utilization was estimated to reach 80% of computer capacity, an airborne delay of 3 minutes was assigned to 1 hour's worth of flight activity being controlled by a center. For those "operational delay days" estimated to reach 100% of computer capacity utilization, a delay penalty of 60 minutes on the ground was assigned to 1 hour's worth of flight activity waiting to depart from local airports serviced by the center; departing traffic from local airports represents about 40% of the service workload for a center. Dollar values per minute of delay were assigned to both the airborne and ground delays estimated by the study in order to yield the total dollar values shown in Table 4.

The dollar figures shown for "System Outages" were based on the record of reliability for #9020 computer equipment provided by the FAA's Airways Facilities Branch and confirmed by the reports of delays caused by computer

system outages compiled by the Administrator's National Aviation System Communications (NASCOM) staff. These outage reports confirm a recent record of approximately 50 NASCOM reported delays per year for the national network of en route centers.

A NASCOM delay is recorded at a facility when delays in excess of 30 minutes are experienced.

With the use of modern computer technology and reliability concepts, it was estimated that the recent outage experience could be reduced by an order of magnitude: from 50 outages a year to 5. The dollar amount for "System Outages" shown in Table 4 reflects this reduction.

The reader interested in the study methodology, assumptions and calculations that led to the results presented on the benefits associated with avoiding the costs of capacity induced delays, should consult Supplementary Report B.5/

5/. Working paper: "The Estimating of Dollar Costs Due to Operational Delays;" AEM-100, Aug. 1981

Table 4. The Dollar Benefits (Avoidance of Costs)
Due To Eliminating Constraints To Computer System: 1982-2011,
By Investment Option
(In Billions of 1981 Dollars, Discounted To The Present)

Investment Option	Support Functions	Cost Avoidance Category: Airborne Delay (80% Capacity)	Cost Avoidance Category: Ground Delay (100% Capacity)	System Outages	Total
2A	0.007	0.191	1.002	0.000	1.20
2B	0.007	0.285	1.498	0.000	1.79
3A	0.007	0.162	0.851	0.000	1.02
3B	0.007	0.145	0.758	0.000	0.91
4A	0.005	0.278	1.502	0.016	1.80
4B	0.006	0.304	1.472	0.018	1.80
5	0.006	0.336	1.432	0.027	1.80
8A	0.005	0.250	1.521	0.025	1.80
8B	0.005	0.250	1.521	0.025	1.80
6	0.003	0.266	1.395	0.016	1.68
7A	0.003	0.274	1.437	0.016	1.73
7B	0.003	0.277	1.453	0.016	1.75
7C	0.003	0.277	1.453	0.016	1.75

It would be appropriate at this point in our discussion to include a few words of caution about how the calculation of dollar benefits shown in Table 4 is to be interpreted. The decision as to which option to choose, like all economic decisions, must be an incremental one. The dollar benefits shown reflect the ability of each investment option to avoid the delay costs associated with a system constrained by the capacity limitations imposed by the current computer design. But, these limitations can be removed by a near term investment option; for example, by option 2B. The (discounted) dollar costs avoided by eliminating computer limitations with this option are shown in Table 4 as $1.79 billion. The same approximate dollar benefits ($1.75 billion) are also assigned to the far term replacement options of options 7B and 7C. Hence, it would appear that the dollar estimates shown in Table 4 conform to the study's summary conclusion that a long-run replacement option is preferred. By misinterpreting the presentation of results for capacity-induced delay benefits shown in Table 4, the far term options which are assigned dollar values on a par with the near term values would seem to be equally preferred.

However, while the over-all study conclusion does recommend that the far term options are, indeed, preferred on the basis of those benefit and cost categories which could be quantified, the single benefit category depicting "capacity-induced delays" does not conform to this general recommendation.

If the dollar values for each investment option shown in Table 4 were examined incrementally, it would indicate that no additional benefits from removing "capacity-induced delays" accrue to any of the far term options. In fact, a small negative increment accrues to these far term options to reflect their later implementation. The effect of "discounting" reduces the total dollar value of benefits received in the future.

It is in the benefit categories of "Increase in Fuel Efficiency" and "Increase in Controller Productivity" shown in Table 2 that the additional (incremental) benefits accrue to the far term options. Note in Table 2 that additional dollar benefits in excess of $4 billion are shown for those far term replacement options capable of reaching fully automated levels of service and providing for improvements in controller productivity and fuel efficiency. If these additions to benefits can be acquired at a cost which is less than $4 billion, the recommendation to invest in the far term options would be upheld. From Table 1A we learn that the additional costs to acquire the far term options are actually estimated at less than $2 billion.

Thus, the presentation of benefits and costs provide logical and consistent recommendations for investments if interpreted incrementally. In interpreting the results shown in Table 4, this means an investment in a full replacement option is not recommended if the end objective of the investment is, merely, to remove the operational delays induced by constrained computer capacity. For the same level of dollar benefits, a far term improvement would be less costly. But, the inclusion of other benefit categories, to be described below, indicates that additional investments are justified to achieve higher system objectives.

III.B. Increase in Controller Productivity; Dollar Savings in Controller Work Force

The normal complement of controllers at the en route centers is approximately 10,500. Through the use of more efficient methods and procedures, the FAA has been able to maintain this level over the past 8 to 9 years despite significant increases in air traffic. However, it no longer appears possible to continue to maintain the controller workforce to today's complement in the face of the expectation of a return in the near future to levels of traffic previously forecast. Recourse must be made to a combined set of FAA's Engineering and Development programs in order to continue to make improvements in controller productivity. The analysis of the benefits and costs associated with the implementation of these programs indicates that the investment to improve controller productivity is justified: the savings in controller workforce are sufficient to pay for the implementation of programs leading to fully automated service and increased controller productivity.

The following Engineering and Development programs designed to provide enhanced levels of automation were estimated to result in a significant reduction in controller staffing--to a total reduction of 50%--when implementation is completed. The percentage breakdown by individual program and date of implementation is shown in Table 5. For the purpose of this analysis, the benefits available from the AERA level of automation were estimated to be available in two phases: an initial phase to be completely implemented in 1992; a full-up phase to be completely implemented in 1994.

Table 5. Savings in Controller Workforce By Program, Year of Implementation and Investment Option

Program	% Savings	Year Implemented	Investment Option
Electronic Tabular Display Capability in Sector Suite	15	1987	all
AERA (initial)	10	1992;1993	6 thru 8;5
AERA (full)	25	1994;1995	6 thru 8;5
	50		

The savings in controller staffing when multiplied by average salary levels estimated for the duration of the program life yielded the dollar value of benefits (cost savings) due to increased controller productivity shown in Table 2, line 3.

A more detailed discussion of the methodology, assumptions and calculations used to estimate this benefit category is provided in Supplementary Report C.6/

III.C. Increase in Fuel Efficiency

With the introduction of proposed Engineering and Development programs it is estimated that savings in the cost of fuel of some 6% could be achieved. These programs are designed to incorporate the following functional improvements capable of yielding substantial amounts of fuel savings:

1. En route Metering. Will provide for any system delays which may be incurred, to be absorbed in a fuel-efficient manner. Included in this functional improvement will be the ability to: (a) better coordinate the flow of traffic into "fix" points, (b) predict aircraft arrival times more accurately, and (c) provide for better sequencing of aircraft and airport runway utilization. A savings of 1.5% of the total fuel bill was estimated for this function.

2. Fuel Efficient Route Planning. With this functional improvement incorporated into an E&D program, more direct flights with fewer altitude restrictions would be made. A savings of 1.5% in fuel was estimated for this function.

3. Flow Planning and Traffic Management. Will provide for more accurate predictions of delays and how they might be absorbed more efficiently. These delay predictions will utilize more

6/. Working paper: "Controller and Maintenance Workforce Savings," Aug. 1981

precise data made available concerning aircraft climb/descent profiles, and estimated times of arrival (ETAs). A savings of 1.5% in fuel was estimated for this function.

4. Strategic Clearance Planning. Will provide for the separation of aircraft from other aircraft rather than achieving separation by allocation to prescribed airspace. There will be an accompanying significant reduction in procedural restrictions. The filing of direct routes will be commonplace. A savings of 1.0% in fuel was estimated for this function.

5. Tactical Clearance Generation. Will provide as close to unrestricted flights as possible with no real time intervention of the controller into the control loop. A savings of 0.5% was estimated for this function.

It should be noted that the decreased percentage in savings available with the functional category just described (Tactical Clearance Generation) reflects the incremental ability to benefit from fuel savings, and is consistent with the method of analysis employed in the study. The assumption is that the four functional levels to improve fuel efficiency have already been installed when the fifth category is evaluated and, therefore, it is more difficult incrementally to obtain the same percentage of savings in fuel from successive programs.

Each of these functional categories designed to improve fuel efficiency were related to the investment options considered in the study and their schedules for implementation. This information is shown in Table 6.

Forecast estimates of aircraft types and total traffic activity were used to estimate total fuel consumption. The forecast of fuel consumption was estimated in constant-value 1981 dollars, and the dollars savings from the implementation of the functional improvements listed in Table 6 resulted in the dollar amount of benefits (cost savings) shown in Table 2, line 4.

A more detailed discussion of the method, assumptions, and calculations used to estimate this benefit category of increased fuel efficiency, is presented in Supplementary Report D.7/

7/ Rucker, R.A. "Estimates of the Fuel Savings Potential of Specific Functional Improvements to the Air Traffic Control System;" The MITRE Corporation, July 20, 1981.

Table 6. Fuel Efficiency Savings By Automated Function, Year of Implementation and Investment Option

Automated Function	% Fuel Savings	Year Implemented	Investment Option
En route Metering	1.5%	1983	All
Fuel Efficient Route Planning	1.5%	1992	5, 6, 7, 8
Flow Planning and Traffic Management	1.5%	1992	5, 6, 7, 8
Strategic Clearance Planning	1%	1994	5, 6, 7, 8
Tactical Clearance Generation	0.5%	1995	5, 6, 7, 8

III.D. Decrease in Maintenance Costs

There are 1,120 technicians in the current 9020 maintenance work force. This force comprises approximately equal numbers of hardware and software personnel. The hardware personnel attend the computer proper as well as the display equipment. The 9020 maintenance work force has remained fairly stable over the years and no significant changes are anticipated.

The potential savings in the maintenance staff were estimated to depend on the individual investment options and implementation schedules considered in the study. A 30% savings was estimated for those investment options achieving automated levels with full replacement with new computer technology; a 15% savings was estimated for hardware only replacements (Option 4).

The savings in workforce multiplied by the forecast of maintenance staff salaries and cited in constant-value 1981 dollars, yielded the dollar savings shown in Table 2, line 5 for each investment option. A more detailed discussion is provided in Supplementary Report C, referenced earlier (reference 6).

IV. Details of Study: Dollar Cost Categories

IV.A. Cost Classifications

The study attempted to estimate the program (life-cycle) costs for each investment option. A convenient, albeit arbitrary, method for categorizing the costs which are likely to occur for each year of a program's 30 year planning horizon is to classify them according to: 1) research and development (R&D); 2) investment (INV); and 3) operating and maintenance (O&M) costs. There is no reason, however, for insisting on precision in the assignment of costs to these categories. Specific designs may choose deliberately to trade-off one cost classification for another. For example, highly reliable equipment might be designed employing a superior grade of materials. The investment option utilizing this design concept might, as a result, have a higher initial investment cost but much lower operating and maintenance costs. The important obligation in the estimating of costs is to be sure to include all of the costs which are necessary for resolving the investment decision at hand, and to display them in an appropriate time-series. This latter requirement reflects the preference for receiving "high powered" (low discounted) dollar benefits and the similar preference for postponing expenditures into "low powered" (high discounted) dollars costs.

The classification of costs into 1) R&D, 2) INV, and 3) O&M is useful, however, because it conforms generally to the pattern of expenditures over time:

1) R&D are "one time" costs typically incurred prior to the implementation phase of an investment option. It is a "front end" (low discount) cost. The major outlays for this category usually end early in a program's planning horizon. These one-time costs are frequently independent of, or, at least insensitive to, the level of investment costs; i.e. the number of installations and their schedule for implementation. It is generally the case that approximately the same costs for research and development have to be expended for either prototype or production quantities of equipment.

2) INV costs depend typically on the number of installations to be made. In addition to the costs for equipment and spares, this category includes such items as training and training-aid costs. These costs usually end with the completion of the implementation phase of a program's life-cycle.

3) O&M are those costs necessary to sustain the original investment in equipment at its nominal (time of purchase) level of performance. These costs are typically for staffing levels and expendable parts, and are represented as recurring annual dollar totals which continue through a program's life cycle.

The "convenience" afforded by attempting to assign all relevant costs to the above named categories is that this assignment provides additional analytical insights to support the choice of a given investment option. These insights are pertinent to a world in which uncertainty exists concerning the level of activity or use which will be imposed on an investment option (i.e., the real world).

If there were no differences in the costs estimated by tallying up the dollar amounts in the various cost categories, and no uncertainty existed concerning traffic activity forecasts or the level of service to be provided, then the distinction between cost categories would be an empty one. It would make no difference, based on costs, as to which option was selected.

However, when forecasts are uncertain and decisions must be made in the face of this uncertainty the assignment of costs to the above named categories has important implications for the selection of an investment option:

IV.B. The Effects Due to Uncertainty; "Leverage," or, Sensitivity to Traffic Forecasts

The recent reduction in flight operations as an aftermath of the air traffic controller's strike, although anticipated as being of temporary duration, has heightened the need to examine how the study's results might be affected by changes of longer duration. The study's conclusions are based on the "best," i.e., the most likely, estimate of future air activity. The question to be resolved is how changeable are these results in the face of uncertain forecasts of aviation activity?

In this section, an attempt will be made to examine the consequences of our traffic forecasts being "off-target;" to estimate the alternative effects of, 1) an optimistic forecast above the nominal expectation; 2) a pessimistic forecast below the nominal expectation. These uncertainties in the traffic forecast will be examined first for their effect on the cost estimates presented below in Table 7 and then, for reasons which the discussion will make clear, this will lead us to an examination of the effects of uncertain forecasts on the benefit categories presented in Table 2. This combined evaluation will enable us to estimate the impact of uncertainty upon the study's general conclusions:

The effects of uncertainty on costs. If a manager making an investment decision was particularly anxious to guard against the risk of over-estimating the level of demand for service--he suspects his forecasts are too optimistic and wishes to guard against this possibility--he would prefer to invest in those options with a high proportion of costs in the O&M category and a low proportion in the R&D and INV categories. He could avoid having the "non-recurring" costs for R&D and "already-in-place" investment in equipment costs being deferred over fewer numbers of users and his average costs per unit served actually turning out to be higher then those based on the original forecast.

On the other hand, if a manager wished to guard against the possibility of a pessimistic forecast--the forecast in his opinion, should be more optimistic than the one reported to him--then his preference would be for an investment option with a greater portion of its total costs included as "non-recurring" or R&D costs. For higher levels of activity, total costs will be deferred over more service units. The average cost per unit of service will be reduced in the face of an unexpected increase in traffic. Further, a small change in the forecast level of traffic may produce a larger percentage effect on average costs per unit.

Table 7. Total Program Costs: 1982-2011
By Functional Category and Investment Option
(in billions of 1981 dollars; discounted at 0.10).

Option	Cost Category	
2A	Computer Replacement	$0.017
	Functions, (1) thru (7)	0.306
	Mode S - ground	0.000
	Mode S - avionics	0.000
	Total:	$0.323
2B	Computer Replacement	$0.055
	Functions, (1) thru (7)	0.306
	Mode S - ground	0.000
	Mode S - avionics	0.000
	Total:	$0.361
3A	Computer Replacement	$0.108
	Functions (1) thru (7)	0.306
	Mode S - ground	0.000
	Mode S - avionics	0.000
	Total:	$0.414
3B	Computer Replacement	$0.036
	Functions (1) thru (7)	0.306
	Mode S - ground	0.000
	Mode S - avionics	0.000
	Total:	$0.342
4A	Computer Replacement	$0.182
	Functions (1) thru (7)	0.306
	Mode S - ground	0.000
	Mode S - avionics	0.000
	Total:	$0.488
4B	Computer Replacement	$0.178
	Functions (1) thru (7)	0.306
	Mode S - ground	0.000
	Mode S - avionics	0.000
	Total:	$0.484

Table 7. Total Program Costs: 1982-2011
By Functional Category and Investment Option
Cont: (in billions of 1981 dollars; discounted at 0.10).

Option	Cost Category	
5	*Computer Replacement	$0.820
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$2.121
6	*Computer Replacement	$0.691
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$1.992
7A	*Computer Replacement	$0.800
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$2.101
7B	*Computer Replacement	$0.716
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$2.017
7C	*Computer Replacement	$0.777
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$2.078

(* Includes costs to provide AERA capability)

Table 7. Total Program Costs: 1982-2011
Cont: By Functional Category and Investment Option
(in billions of 1981 dollars; discounted at 0.10).

Option	Cost Category	
8A	*Computer Replacement	$0.807
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$2.108
8B	*Computer Replacement	$0.843
	Functions (1) thru (7)	0.306
	Mode S - ground	0.168
	Mode S - avionics	0.827
	Total:	$2.143

(* Includes cost to provide AERA capability)

Thus, uncertain traffic forecasts have a high "leverage" effect on costs. Investment decisions may be sensitive to this effect. The assignment of costs into "non-recurring" (R&D and investment) and "recurring" (operating and maintenance) provides am estimate of this "leverage" effect.

Since all of the costs shown in Table 7 are of the "non-recurring" variety, it would appear that the study's general conclusion that the far term options are preferred is heavily dependent on the forecast of traffic activity. In particular, it is important to estimate the impact of the forecast being wrong in the direction of being too high. If traffic activity does not meet nominal expectations, the leverage effect of non-recurring costs spread over fewer flight operations could be sufficient to negate the conclusion that the far term options are preferred. However, further examination of the costs differences which are shown in Table 7 reveals that not all of the costs in the "recurring" category were included. It was merely an arbitrary decision that assigned the traditional recurring cost classification of savings in the FAA's ground system's annual operating costs (due to the estimated increase in the category of "Controller Productivity") to the benefit side of the ledger in Table 2. If the estimated reductions in controller staffing were transferred from the benefits account to the cost account, a difference of \$1.27 billion between the long and near term options (\$1.98 billion for the long-term; \$0.71 for the near term options shown in table 2, line 2) would now be classified in Table 7 as a difference in "recurring" costs. The "leverage" effect on costs resulting from the high proportion of "non-recurring" costs due to the failure to meet nominal forecast expectations, would be reduced considerably.

In the same way, the transfer of the dollar amounts for increased fuel efficiency (resulting in lower aircraft operating costs) and for reduced maintenance costs (resulting in lower ground system operating costs) from the benefits side of the ledger to the cost side, would also serve to dampen the preliminary conclusion that the study's results are likely to be upset by the "leverage" cost effect resulting from an unexpected downturn in the forecast of aviation activity.

The above discussion indicates that the "effects of uncertainty on costs" cannot be evaluated in isolation. It is necessary to examine the concomitant effects of benefits; more particularly, on the difference between benefits and costs. When viewed in this combined light, the leverage effect on average costs per units of user activity resulting from an unexpected reduction in forecast will not be of sufficient magnitude to offset the study's conclusion that the far term, full replacement, options are the preferred economic choices. Other arguments are offered to support this view.

Another and more important reason for believing that the study's conclusion will hold up even if there is despite a possible downturn in the forecast of traffic, is the fact that the measure of activity that impacts directly upon the calculation of dollar benefit and costs is not annual numbers of IFR flight operations. The program costs to implement and maintain a network of en route centers depend, instead, on the ATC system configuration; the number of centers in a national network and the number of computer installations to be modified or replaced.

The number and level of automation of computer installations required for each option is generally fixed in the short run and is affected indirectly, if at all, by changes in the numbers of annual IFR operations serviced by the ATC system. The computer replacement costs shown in Table 7, line 1, which differ by some $0.6 billion between the near term and far term options represent an increment in costs to be borne by the FAA as manager and custodian of the ATC system. This cost differential is not likely to be offset by a modest uncertainty in the FAA's "best" forecast of the numbers of IFR aircraft using the system.

In the same way, the relevant measure of activity for estimating the differences in costs to the aviation users of the ATC system is not annual IFR operations, but the size of the aircraft fleet, or the population of aircraft owners who choose to purchase more automated avionics equipment. The sensitivity of this population to forecasts of operations depends on the class of aircraft owner under discussion. In general, however, neither the airline operator nor the general aviation aircraft owner's choice of avionics equipment will be sensitive to the number of operations that are forecasted.

For the scheduled airline operator, the size of the air carrier fleet has remained fairly stable for a prolonged period of time; increases in passenger travel being accommodated to a significant degree by the use of larger-sized aircraft. The forecast is for modest increases only in the size of this fleet. Hence, the costs for increased avionics costs shown in Table 7 will not be affected to any large extent by changes in the level of traffic activity forecast for the major air carriers.

To a somewhat lesser degree, the population of general aviation owners choosing to equip their aircraft with more automated avionics equipment will, likewise, not be affected directly by the forecast growth in annual IFR operations. Instead, the choice will depend on the extent of their desire to receive full ATC service. The population of general aviation aircraft owners currently equipped with the latest avionics equipment will probably avail themselves of the opportunity to receive additional service through automation. Hence, the additional costs to both the airline and the general aviation user for Mode S avionics--some $0.83 billion which are included in options (5) thru (8), and are shown in Table 7, line 4--are not likely to be sensitive to changes in the forecast of annual IFR operations.

The remaining cost category shown in Table 7 is for a standard package of seven automated "functions" to be included in the ground system computer costs to be borne by the FAA, and added to all investment options--near term as well as far term--regardless of traffic activity. This means that the zero difference in costs between options shown in Table 7, line 2 for this package of functions will continue to hold regardless of some uncertainty in the forecasts of traffic activity. In summary, the cost categories shown in Table 7 for both the aviation user and the FAA will not be affected in a significant way by a modest downturn in traffic activity.

The effects of uncertainty on benefits. On the benefits side of the ledger, the story regarding the sensitivity of the dollar differences between options shown in Table 2 to changes in forecasts of activity is a mixed one:

Differences in dollar benefits favoring the study's conclusions that the long-term options are preferred over the near term options can be seen in two categories only; 1) "Increase in Controller Productivity," and 2) "Increase in Fuel Efficiency." The former category accrues to the FAA in the form of reductions in controller staffing costs to maintain its network of ground stations; the latter category benefits the aviation users in the form of reduced fuel costs to operate their aircraft.

The FAA's savings in staffing costs due to an increase in controller productivity are estimated as being relatively insensitive to changes in traffic activity. These costs depend upon the center's location, degree of sectorization of the en route airspace, level of automation, and the resulting staffing standards. The relationship between controller staffing levels and traffic activity is a statistically discrete one in which savings are available in binary ("all or nothing") amounts as flight activity increases: no savings occur until a discrete increase or decrease in activity has been reached to cause a change in the center's configuration or sectorization, etc. which is sufficient to affect staffing levels. Thus, there is a built-in rigidity in the ground system cost savings shown as benefits to the FAA in Table 2.

On the other hand, the dollar benefits in "Fuel Efficiency" shown in Table 2 are highly dependent on the annual forecasts of IFR operations used in the study. These benefits, in the form of fuel-cost savings, differ by almost $3 billion between the far term and near term investment options (approx. $5 billion in fuel efficiency benefits are shown for the full-replacement options; about $2 billion for the near term options). Since, this is the most important benefit category for which dollar calculations were attempted, the question remains as to whether the study's conclusion that the long-term options are preferred economically will continue to hold in the face of an uncertainty in the forecasts of traffic activity.

From Table 2 we learn that the minimum difference in total dollar benefits between a long-term and a near term option is $3.82 billion: The dollar benefits for far term option (5) is $8.51 billion; the benefit for near term option (4B) is $4.69 billion. From table 7 we learn that the difference in costs between these two options is $1.64 billion; $2.12 billion is the additional cost over the base option to implement option (5); $0.48 billion is the similar cost for option (4B).

The net benefits (benefits less costs) that separate these two options are, \$3.82 - \$1.64, or \$2.18 billion. It would, therefore, take a reduction of \$2.18 billion in the additional benefits shown for the far term options to reverse the study's conclusion that this class of options is preferred economically.

If one were to make the conservative assumption that only the \$4.77 billion in dollar benefits for "increased fuel efficiency" shown for option (5) in Table 2 would be reduced by a downturn in the forecasts of traffic activity (the \$2.13 billion in these benefits shown for option (4B) is assumed to continue) it would take an unexpected curtailment in traffic growth in excess of 50% to offset the \$2.18 billion in fuel efficiency benefits which currently favor the far term option. Reducing the \$4.77 billion in fuel benefits shown for option (5) by one-half, still yields benefits which favor this option by an amount in excess of \$2.18 billion; the amount needed to break even.

But, a reduction in forecast traffic growth which is in excess of 50% would not only result in an unfavorable verdict with regard to the far term computer replacement options, it would also place all programs for engineering and development in an untenable economic position. In short, any permanent reduction in future traffic activity of such dimension would be catastrophic to civil aviation.

The study's general conclusion is that a full replacement option is preferred over the base option to continue with the present system. The study's verdict is that the full replacement option is also preferred over the near term solutions. These conclusions are not significantly sensitive to changes (reductions) in aviation traffic forecasts. They depend only on the realistic assumption that the aviation industry will continue to grow at a rate that is reasonably consistent with its past history.

IV.C. Estimates for R&D and Investment Costs

The estimates shown by investment option have been grouped according to: 1) the costs needed to replace or modify the computer; and, 2) the costs to equip the en route center with the computer-generated capability for providing more service to users with newly enhanced levels of automation. The automation levels were estimated as being available in two packages, standard and advanced.

The standard package of automated functions include the following components:

(1) Conflict Alert for VFR Intruders (CA VFR)

(2) Conflict Resolution Advisories (CRA)

(3) En Route Metering (ERM)

(4) Electronic Tabular Display Capability in Sector Suite Interface

(5) Mode S Interface

(6) Center Weather Service Unit (CWSU) Interface

(7) Terminal Information Display System (TIDS) Interface

The advanced package includes the following AERA functions:

(8) Direct/Fuel Efficient En Route Planning

(9) Flow Planning and Traffic Management

(10) Strategic Clearance Planning

(11) Full Tactical Clearance Generation and Execution

For a more detailed description of each of the above functional improvements, see Appendix 1, Section 2.4. 8/

All of these functions are included as a package of improvements available with each of the investment options considered in the study.

The time series of dollars costs for development ($D) and implementation or investment ($I) which is scheduled to be fully completed in the year 1989 is shown in Table 8 for each functional improvement. The grand total of 8 years of expenditures (1982-89) for this package of improvements was calculated as $469 million in 1981 dollars (undiscounted). The discounted dollar total is $306 million; shown in table 7 line 2 for all options.

The full replacement options 5 thru 8 are provided with an additional "advanced" automation improvement package: AERA, or full en route automation capability. These costs are included in the computer replacement costs shown in Table 7, line 1.

The costs to the FAA for Mode S ground equipment and the costs to the aviation user for avionics equipment are shown in Table 9. The ground equipment costs represent the investment needed to implement a national network of Mode S ground stations; implementation to begin in 1987 and to be completed by the year 1992. The costs to the aviation user represent the alternative, additional, expenditures required to acquire Mode S avionics in place of ATCRBS. Those aviation users who were forecast to be equipped with ATCRBS avionics equipment, including those users entering the aircraft population for the first time and deciding to install this equipment, were estimated to install Mode S equipment instead.

8/ "Meeting En Route Air Traffic Control Requirements in the 1980's and 1990's - An Option Analysis" Appendix 2 of this submission.

TABLE 8. TIME SERIES OF DOLLAR COSTS TO DEVELOP (D) AND IMPLEMENT (I) FUNCTIONAL IMPROVEMENTS
(IN THOUSANDS OF 1981 DOLLARS)

Fiscal Years: 1982 - 1989

	1982	83	84	85	86	87	88	89	1982-89
(1) Conflict Alert, VFR									
$D	139	343	160						642
I	--	--	401						401
	139	343	561						1043
(2) Conflict Res. Advisory									
$D	487	557	401	--					1445
I	--	--	--	373					373
	487	557	401	373					1818
(3) En Route Metering									
$D	426	429	481	224					1560
I	--	172	120	112					404
	426	601	601	336					1964
(4) ETABS/Sector Suite									
$D	1390	815	321	149	69	--			2744
I	--	--	--	--	39598	17375			56973
	1390	815	321	149	39667	17375			59717
(5) Weather Interface									
$D	139	214	281	840	--	--			1474
I	--	--	--	--	--	23295			23295
	139	214	281	840	--	23295			24769
(6) Mode S Interface									
$D	741	--	--	--	555	515	--	--	1811
I	6209	34305	--	--	83218	70013	69988	50000	313733
	6950	34305	--	--	83773	70528	69988	50000	315544
(7) TIDS Interface									
$D	741	1072	1163	933	659	386	--		4954
I	--	--	--	--	19834	25290	14286		59410
	741	1072	1163	933	20493	25676	14286		64364
Total $D	4063	3430	2807	2146	1283	901	--	--	13475
I	6209	34477	521	485	142650	135973	84274	50000	454589
	10272	37907	3328	2631	143933	136874	84274	50000	469219

TABLE 9. TIME SERIES OF DOLLAR COSTS TO ACQUIRE MODE S FUNCTION
GROUND AND AVIONICS EQUIPMENTS: OPTIONS 5 THRU 8
(IN MILLIONS OF 1981 DOLLARS)

	1984	85	86	87	88	89	90	91	92	93	94....2011	1984-2011
MODE S												
Ground	--	--	--	56.4	56.4	56.4	56.4	56.4	56.4	--	-- --	338.4
Avionics	137.2	189.3	186.7	183.7	71.0	71.3	73.6	74.8	75.3	75.8	45.8....45.8	1963.1
Total:	137.2	198.3	186.7	240.1	127.4	127.4	130.0	131.2	131.7	75.8	45.8....45.8	$2301.5

V. Combining Benefits and Costs: Automating the Analysis Process.

In order to facilitate the comparison of dollar benefits and costs, the study decided to automate the analysis process itself. Numerous assumptions concerning dates of implementation, traffic activity forecasts, rates of inflation, discount factors, etc. must, of necessity, be included in any analysis. The dollar estimates for benefits and costs summarized in section II, Table 1 and 1A, were based on a nominal (best forecast) set of assumptions concerning the state of the future world pertinent to a consideration of a computer replacement program. However, by automating the analysis process, the study has the ability to generate dollar estimates based on any revised set of assumptions; to provide view-graphs and tables on demand for these proposed revisions.

A summary presentation of results based on the use of a nominal or "best estimate" set of assumptions is included in this report as Figures 1 thru 13. They present a time flow of annual aggregate totals of benefits and costs for all investment options considered in the report for the length of the planning horizon; the years 1982-2011.

In addition to the summary presentations, more detailed information by individual category of benefit or cost can be provided for each option. A sample package of data for option 7C is shown in Figures 14 thru 26. All dollar amounts are in constant value 1981 dollars.

A detailed description of the method and assumptions used in the study's computer model of quantified benefits and costs is contained in Supplementary Report F.9/

9/ "Benefit, Cost Studies Methodology;" Seiler, Karl III, October 1981.

FIGURE 1. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 2A AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

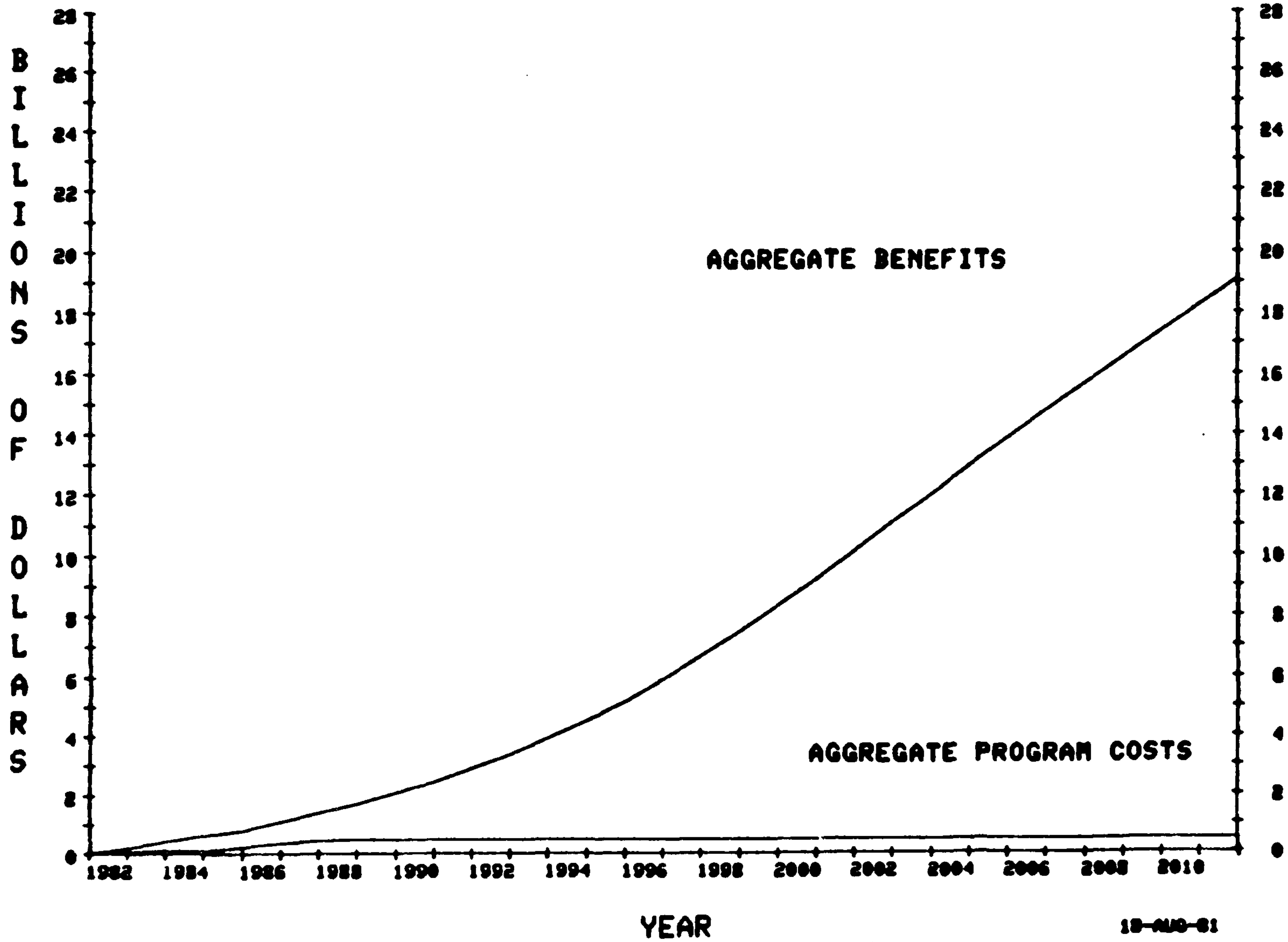


FIGURE 2. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 2B AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

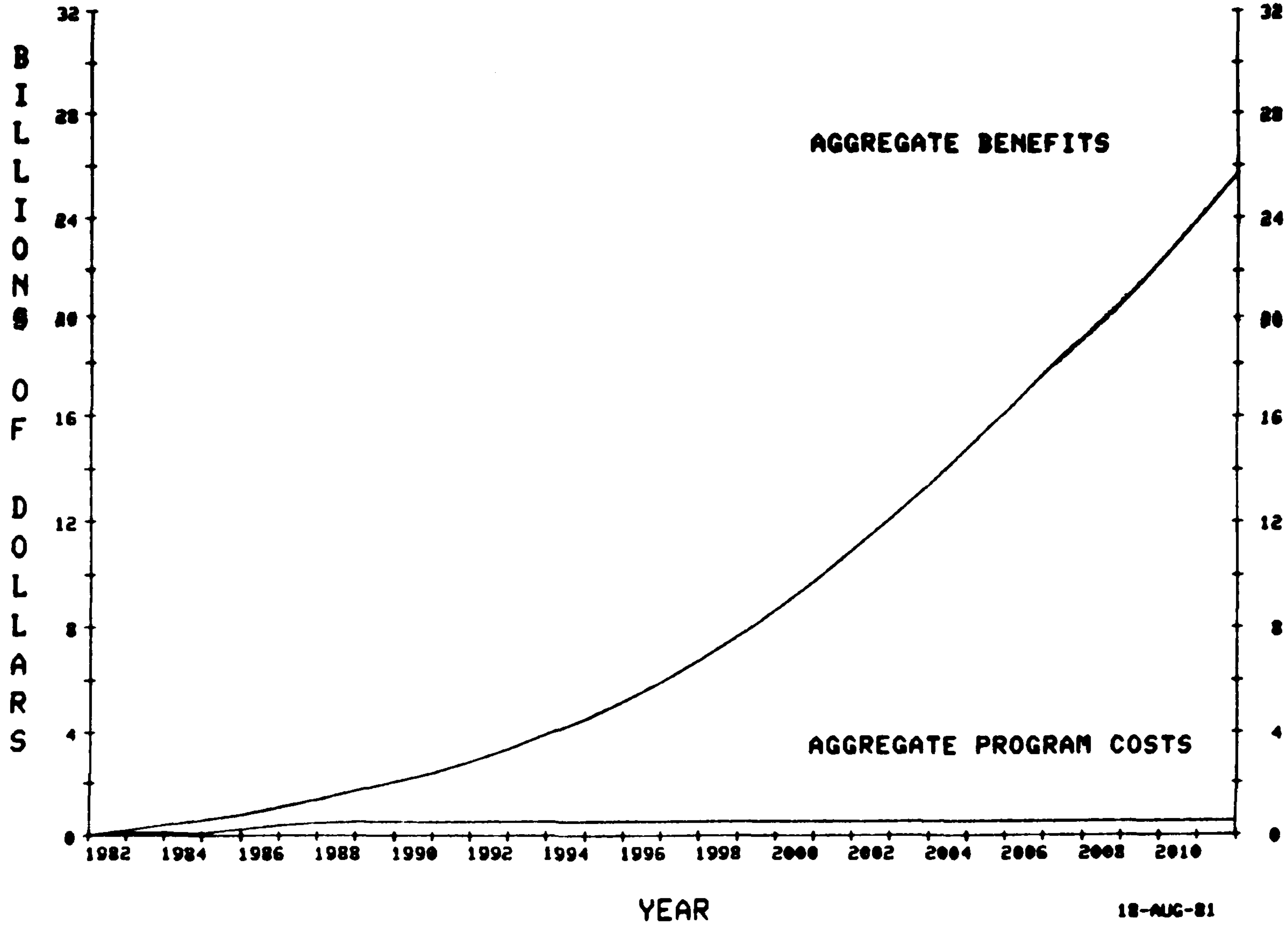


FIGURE 3. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 3A AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

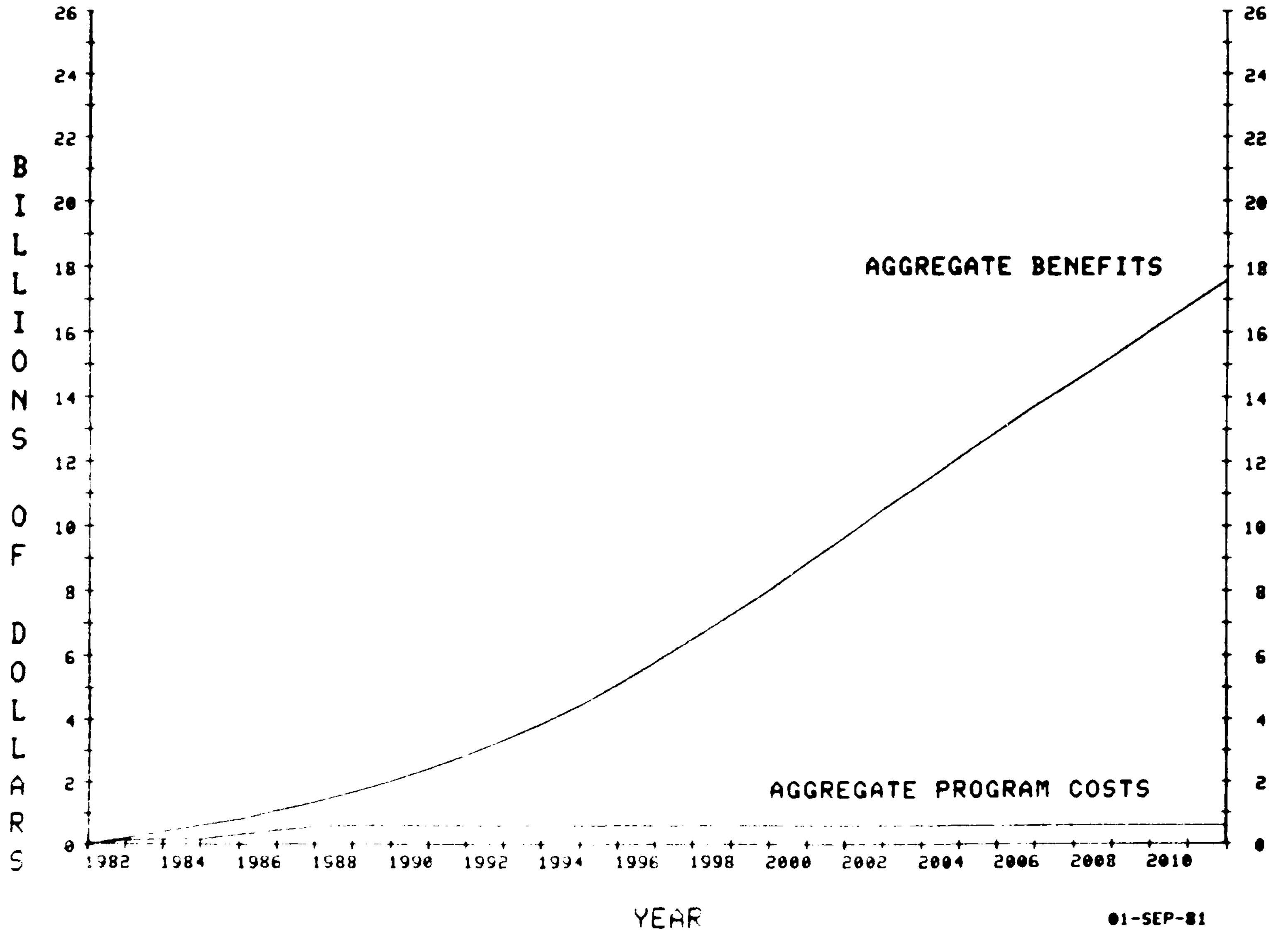


FIGURE 4. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 3B AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

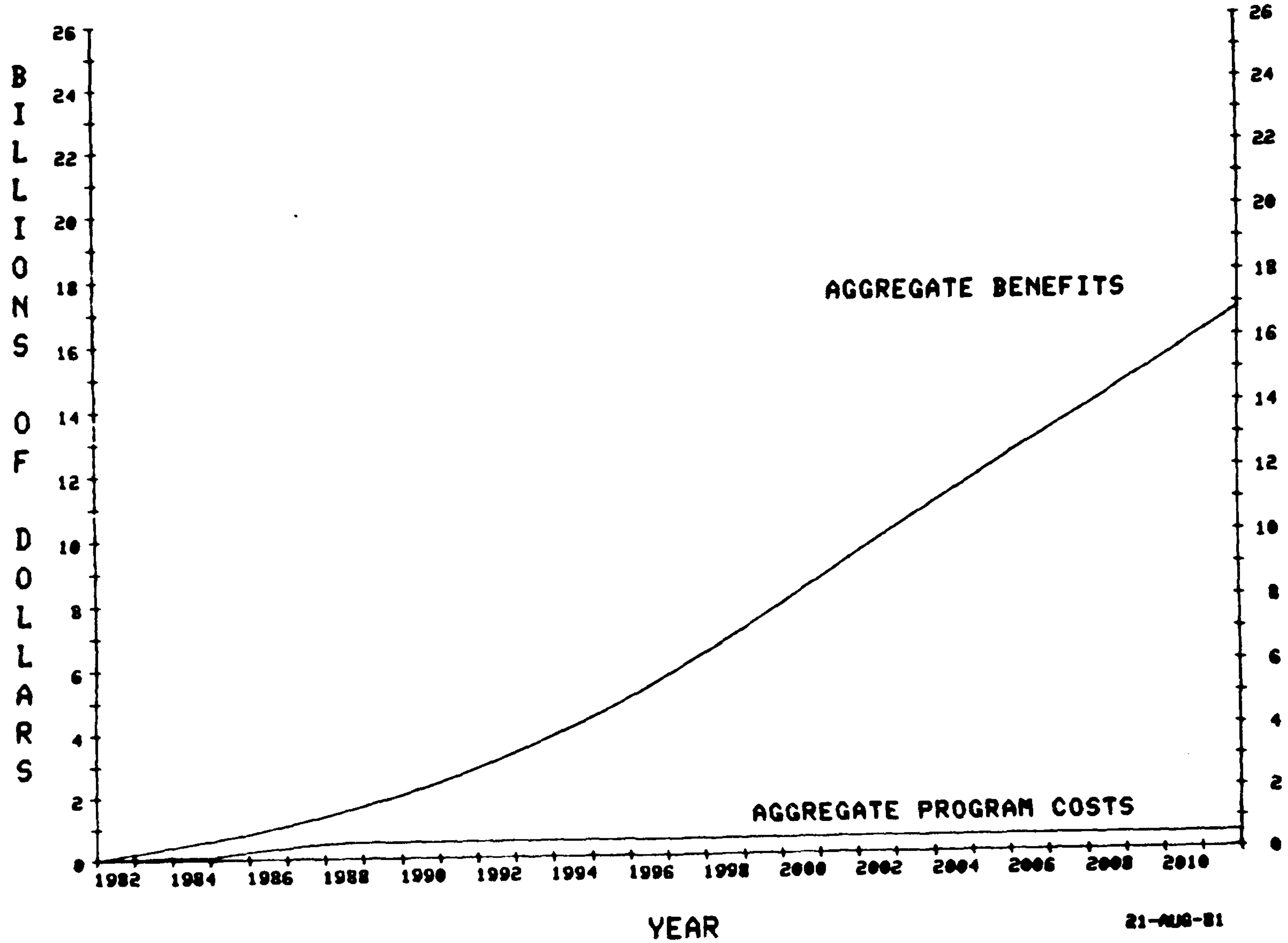


FIGURE 5. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 4A AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

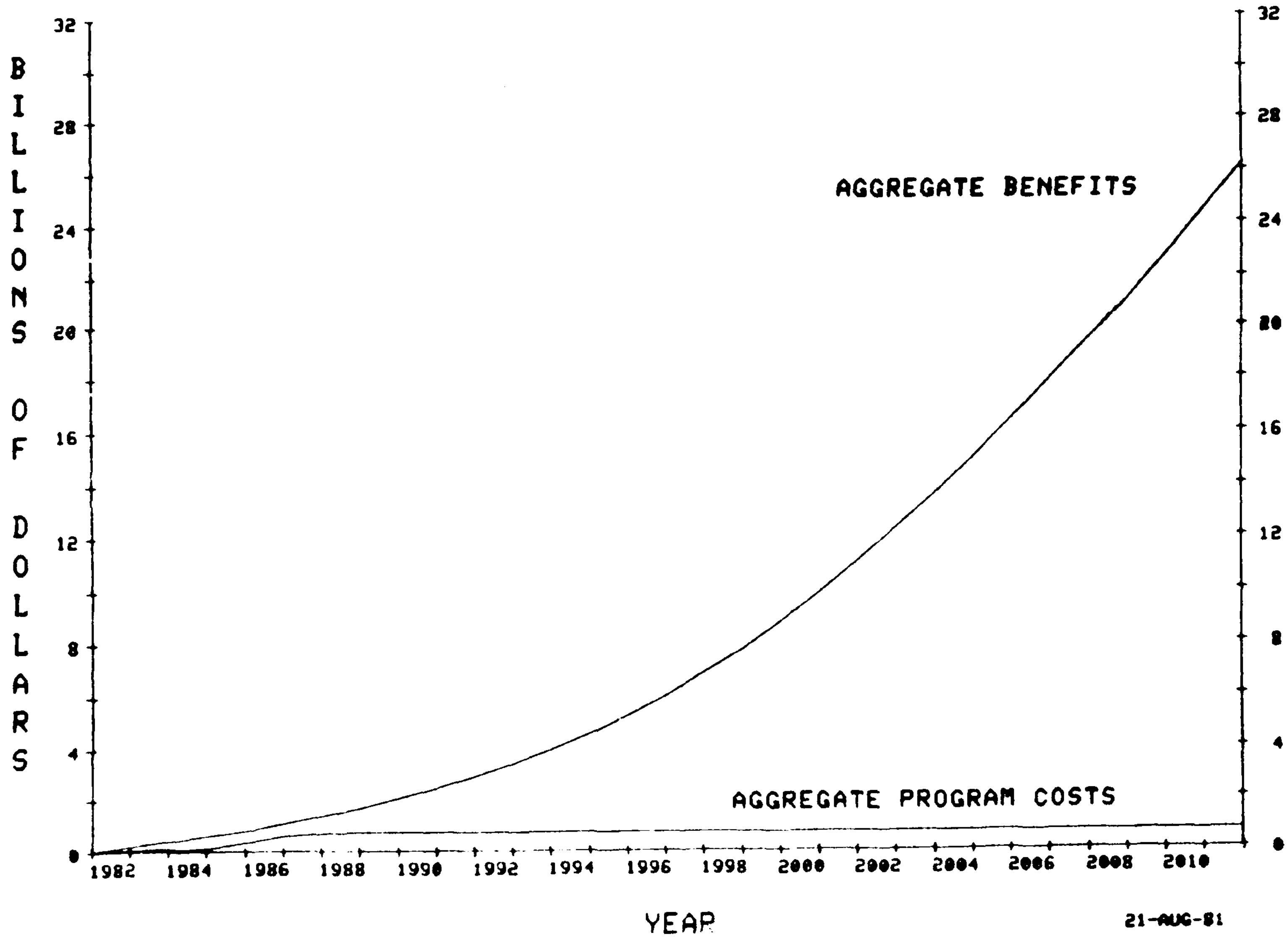


FIGURE 6. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 4B AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

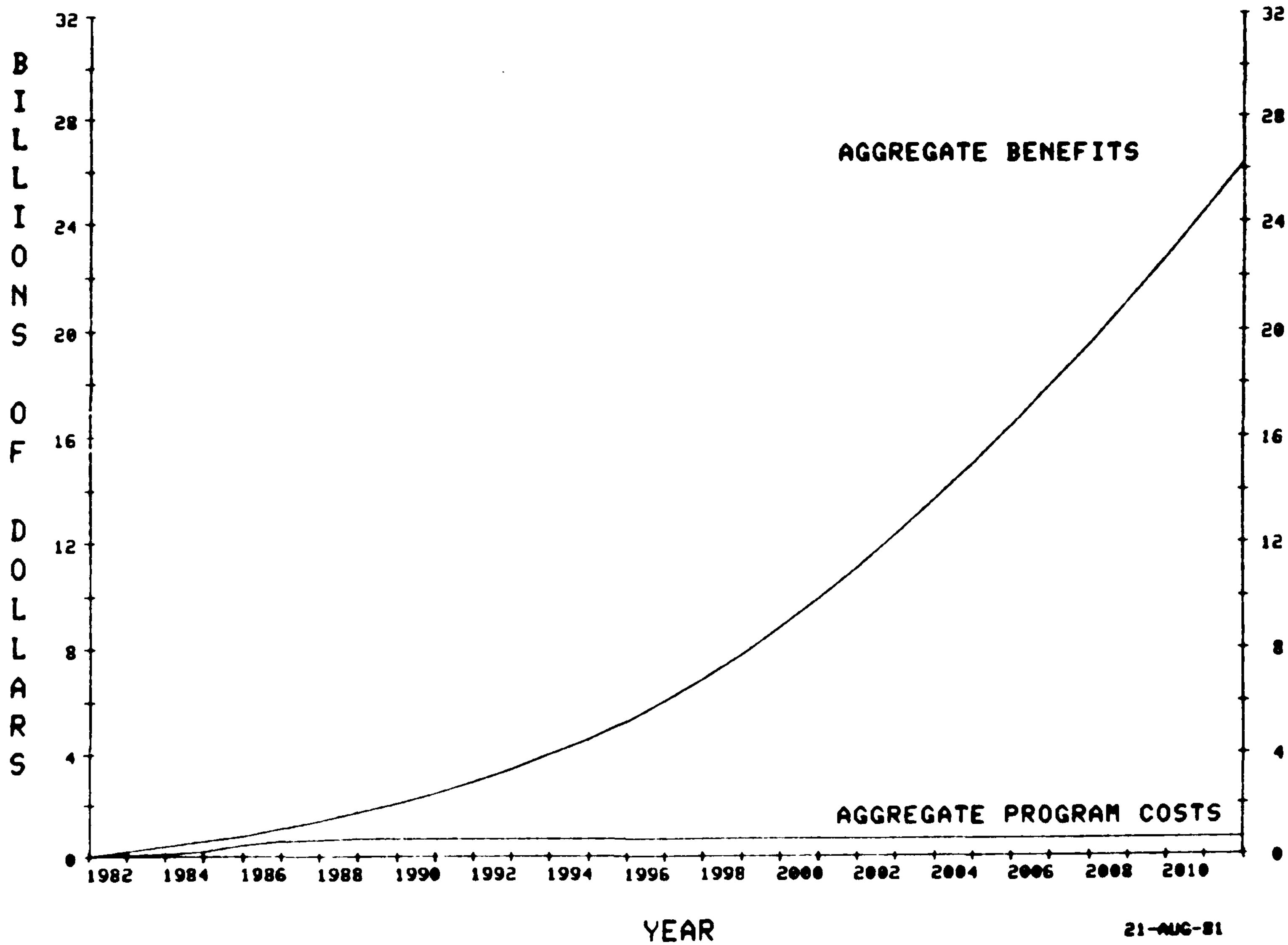


FIGURE 7. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 5 AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

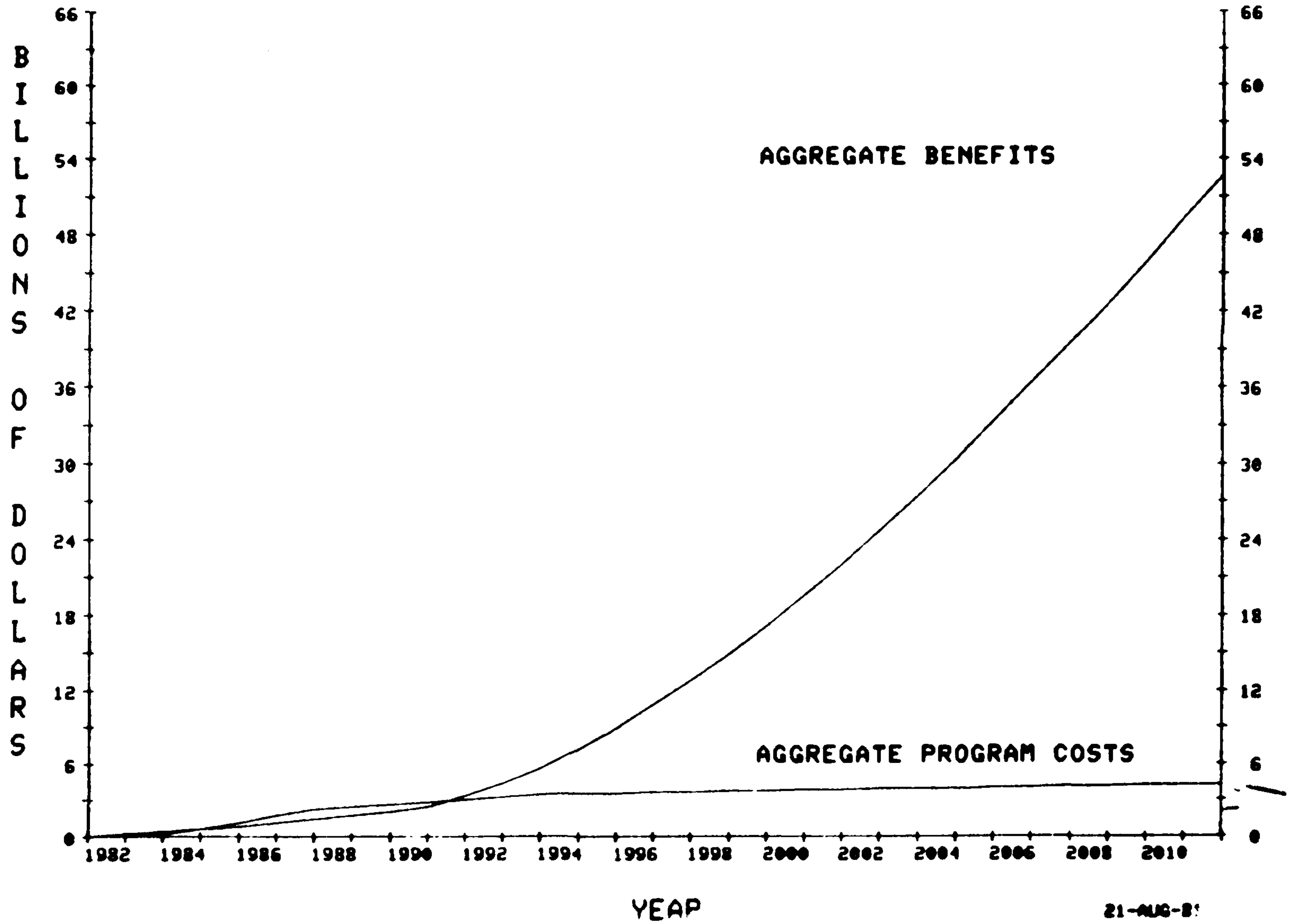


FIGURE 8. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 6 AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

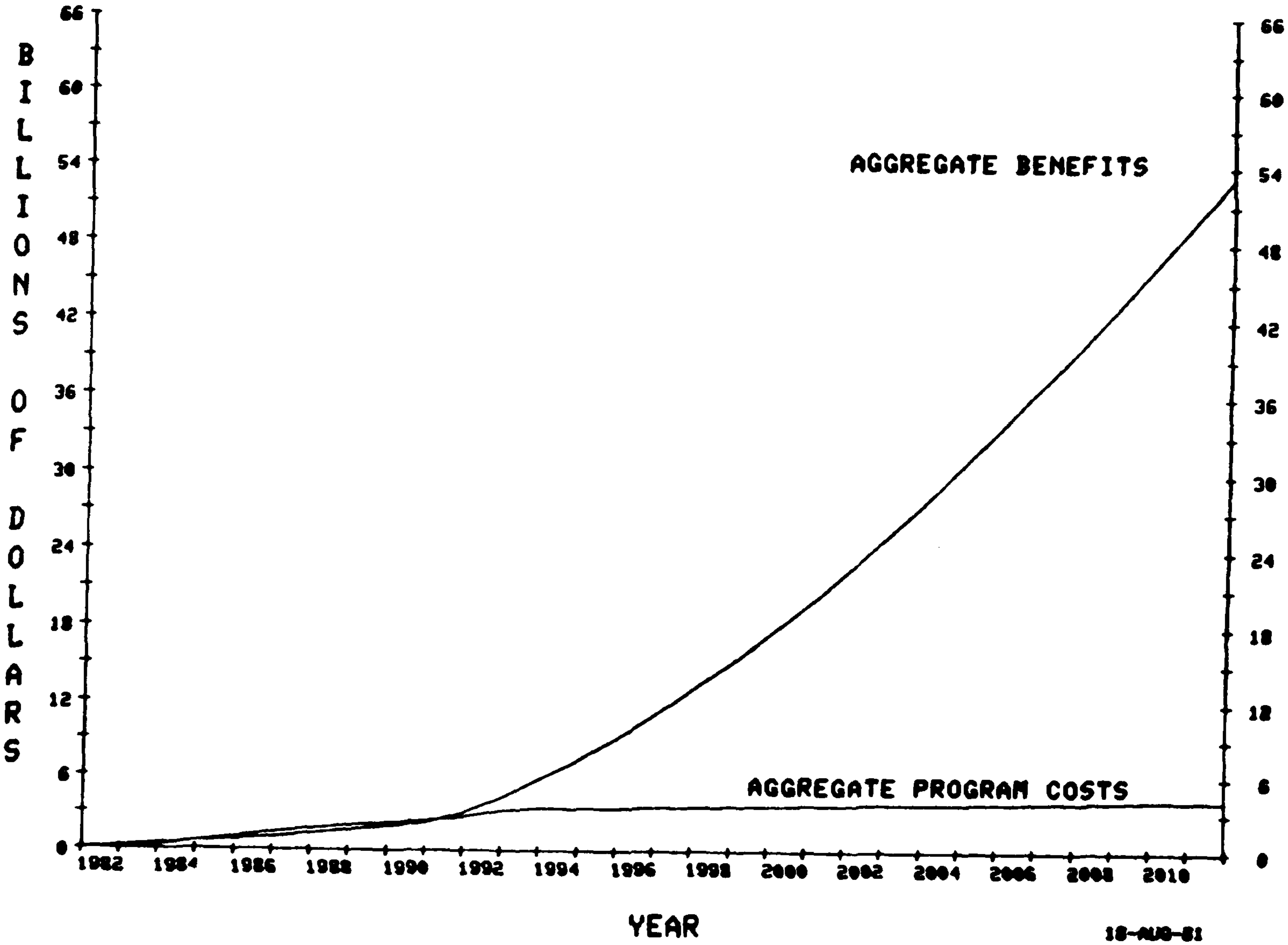


FIGURE 9. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 7A AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

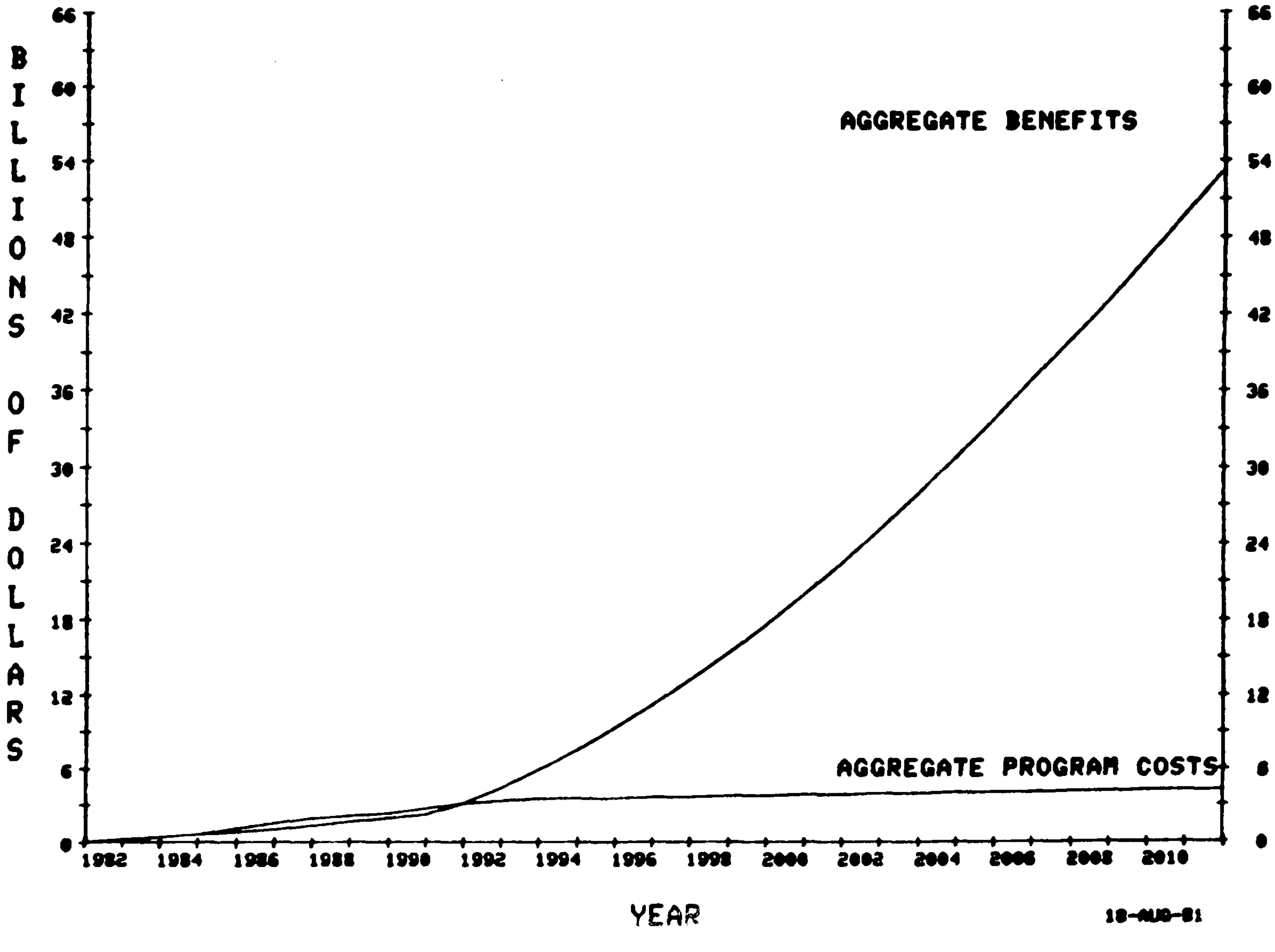


FIGURE 10. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 7B AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

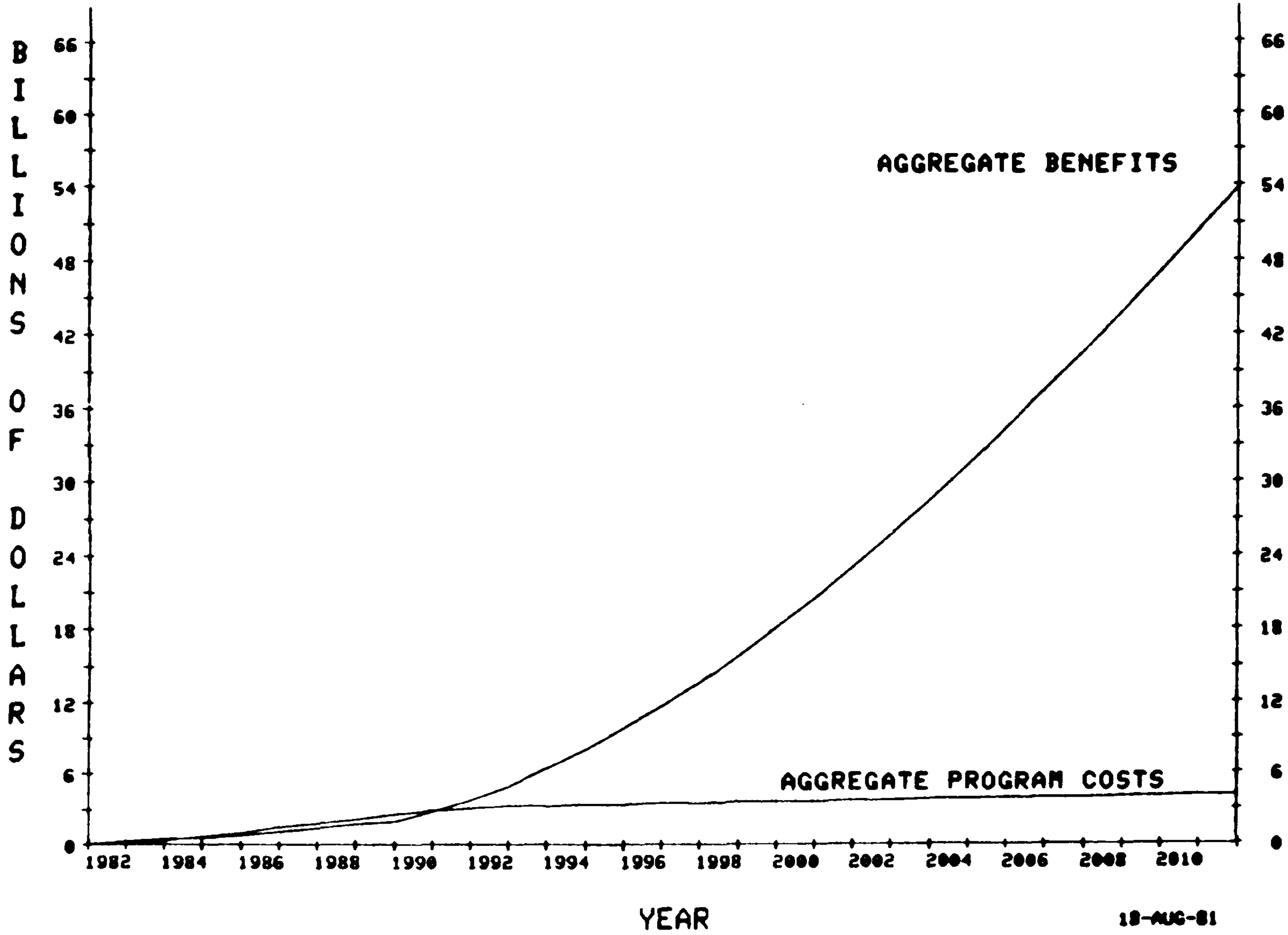


FIGURE 11. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 7C AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

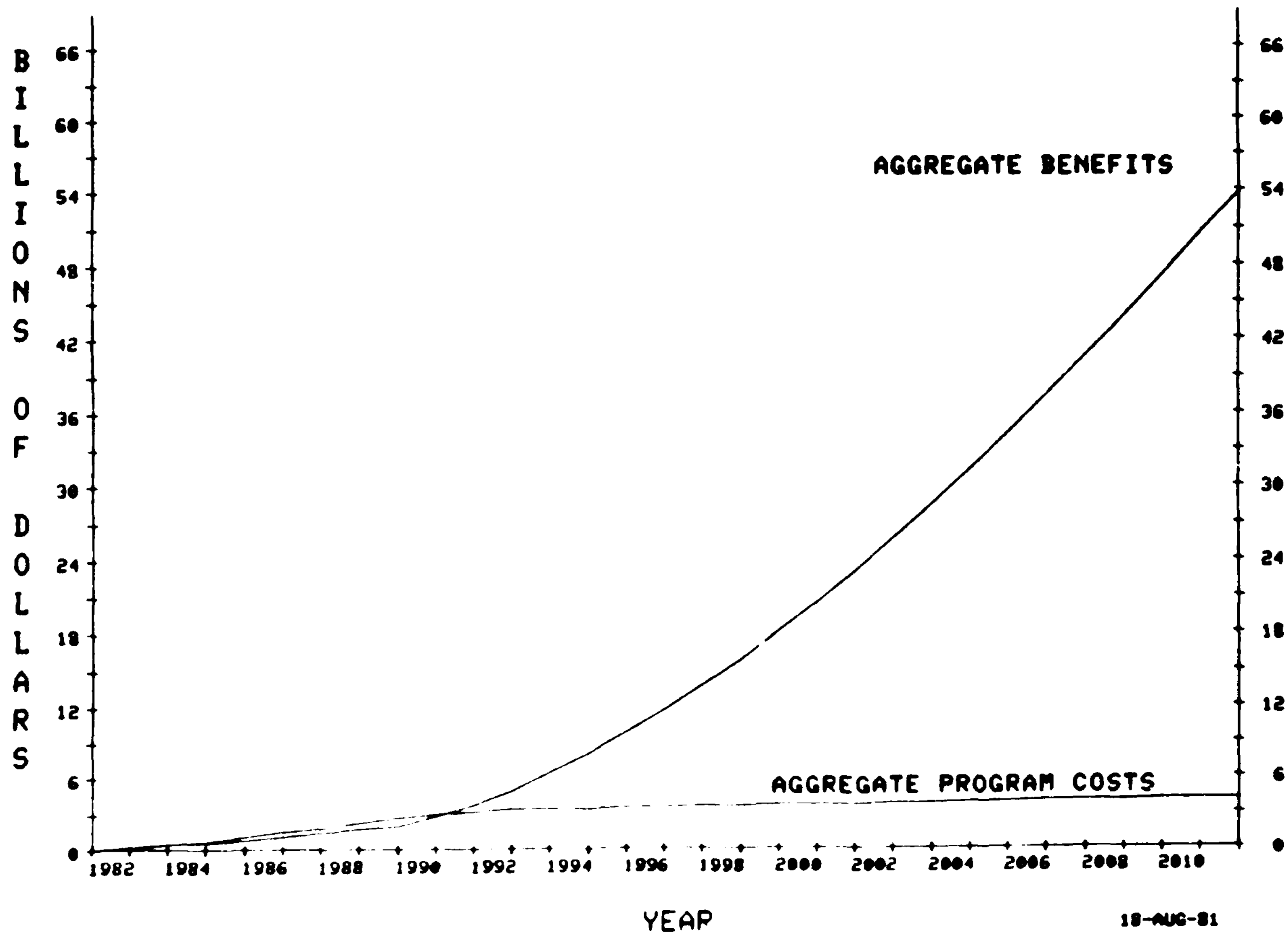


FIGURE 12. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 8A AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)

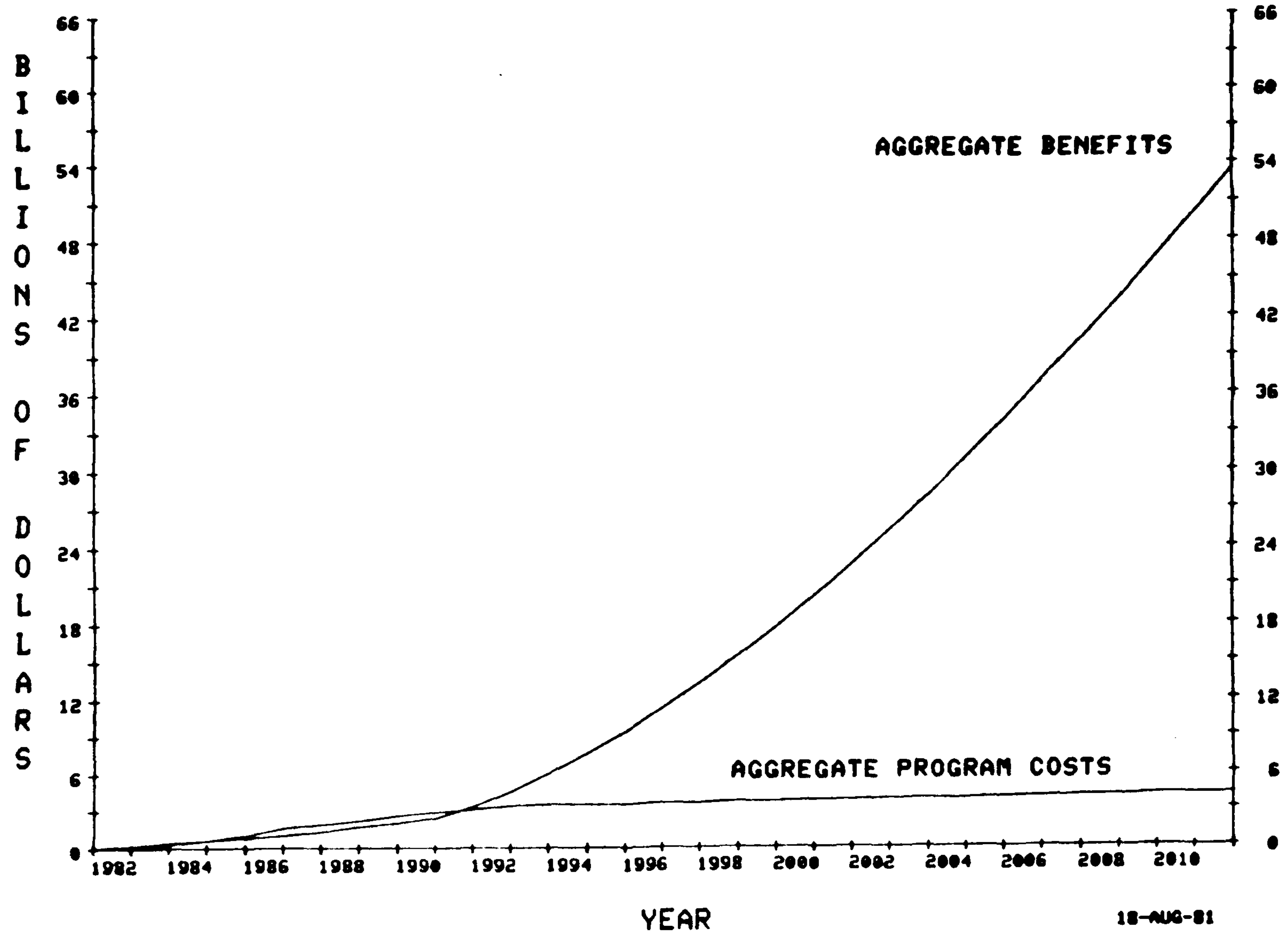
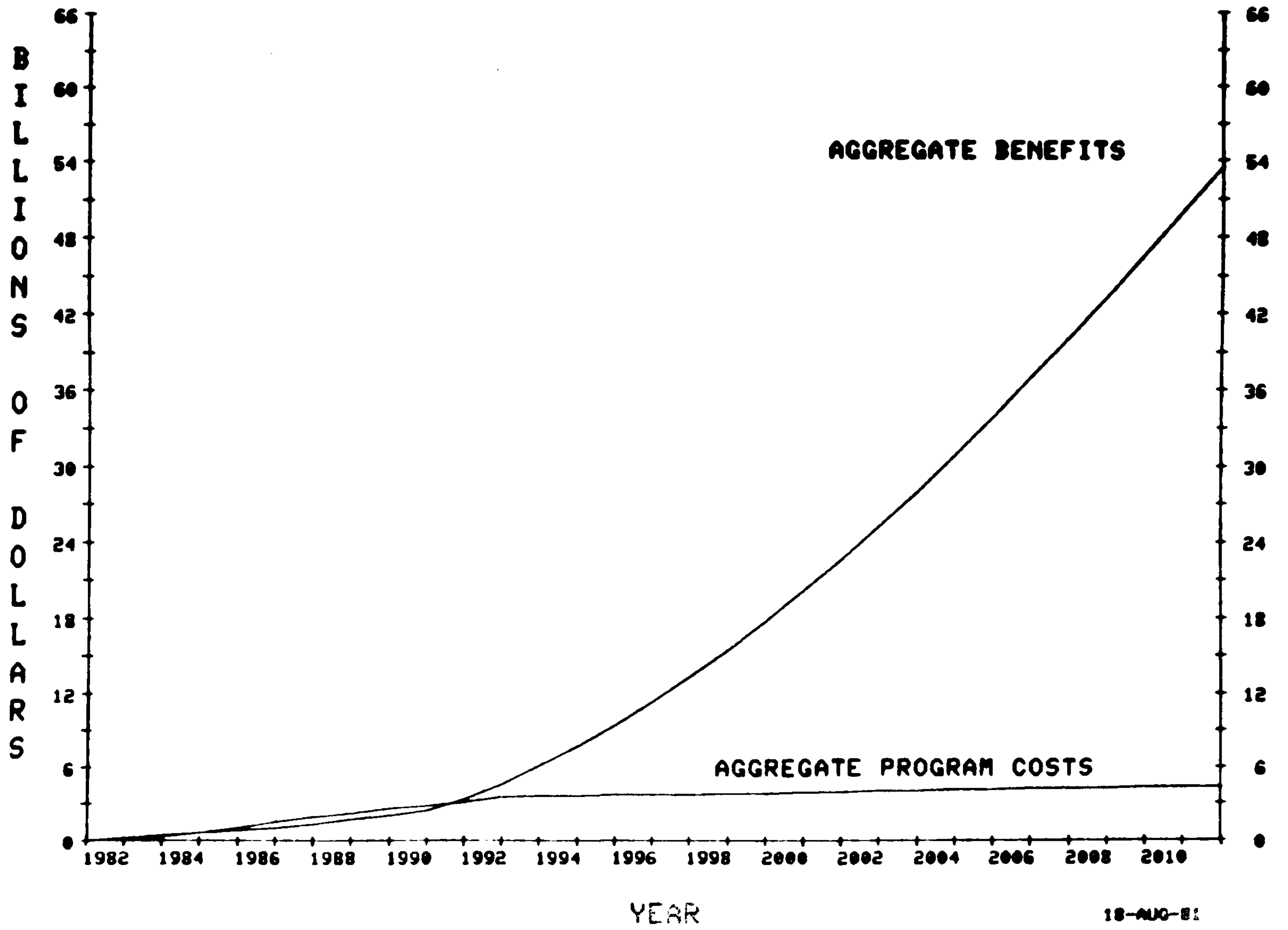


FIGURE 13. ACCUMULATED DOLLAR BENEFITS AND COSTS: 1982-2011
DIFFERENCE BETWEEN OPTION 8B AND BASIC
(IN BILLIONS OF UNDISCOUNTED 1981 DOLLARS)



Titles of Detailed Information Available by Computer Model
Individual Benefit and Cost Categories; by Investment Option
Example: Option 7C

Figure 14. Benefits vs. Costs
(7c) Replacement 5-2-1 vs. Basic
Present Discounted Value (10.0% Per Year): 1982-2011
(1981 Dollars)

BENEFITS (BILLIONS OF DOLLARS)	
CONTROLLERS	1.976
DELAY	1.754
FUEL	5.045
MAINTENANCE	0.064
TOTAL BENEFITS	8.839
COSTS (BILLIONS OF DOLLARS)	
COMPUTER REPL.	0.777
MODE S-AVIONICS	0.250
MODE S-GROUND	0.131
FUNCTIONS 1/	0.306
TOTAL COSTS	1.464
BENEFIT/COST RATIO	6.037

1/ CA FOR VFR INTRUDER, CRA, ERM, ETABS, CWSU, MODE S INTERFACE, TIDS

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Figure 15. Benefit Less Cost Projection
(7c) Replacement 5-2-1lvs. Basic
Given Year (Undiscounted) 1981 Dollars

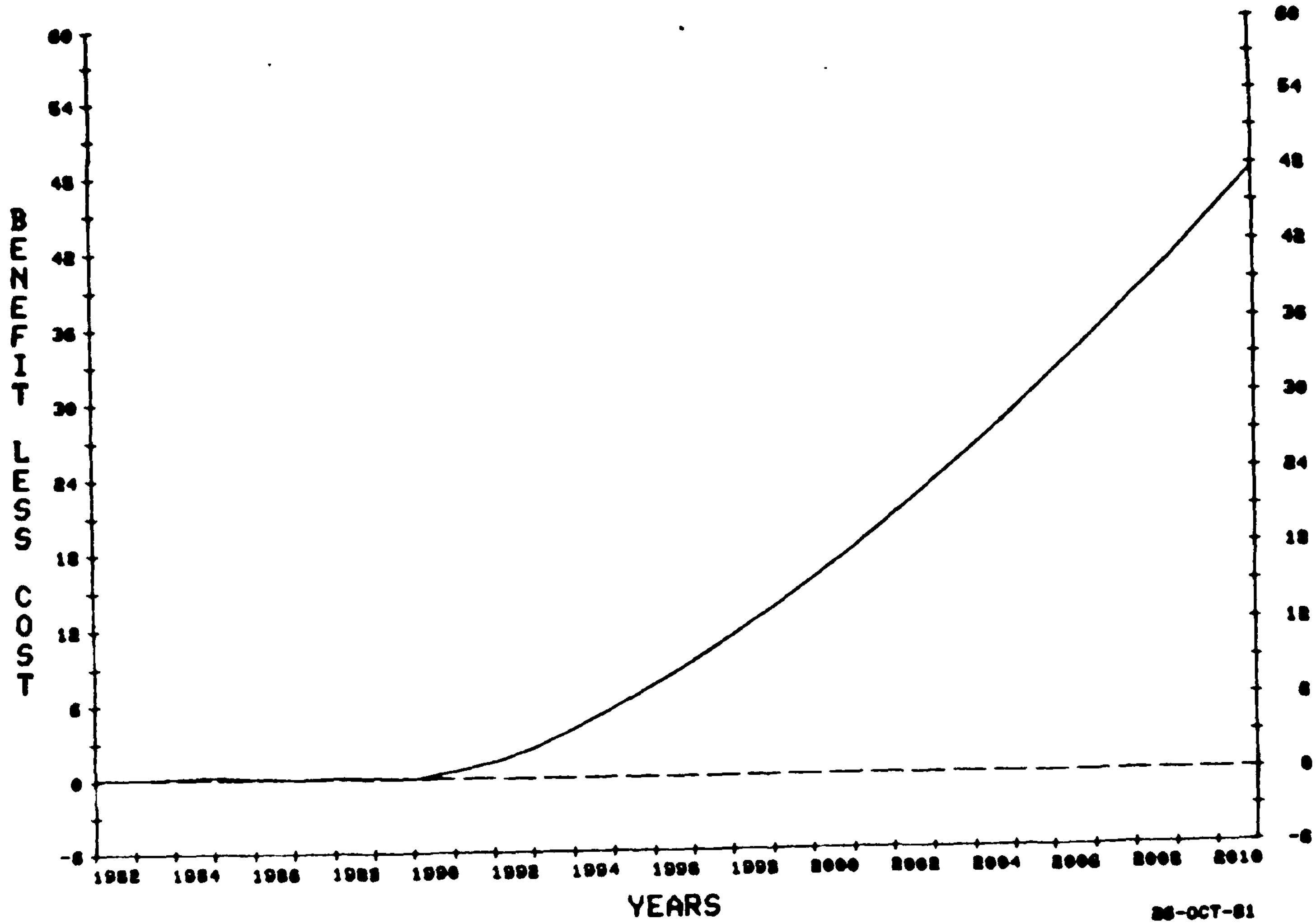

Figure 16. Benefit Category: Controller Productivity
Annual Controller Work Force Growth Projection of Positions
(7c) Replacement 5-2-1-1 vs. Basic

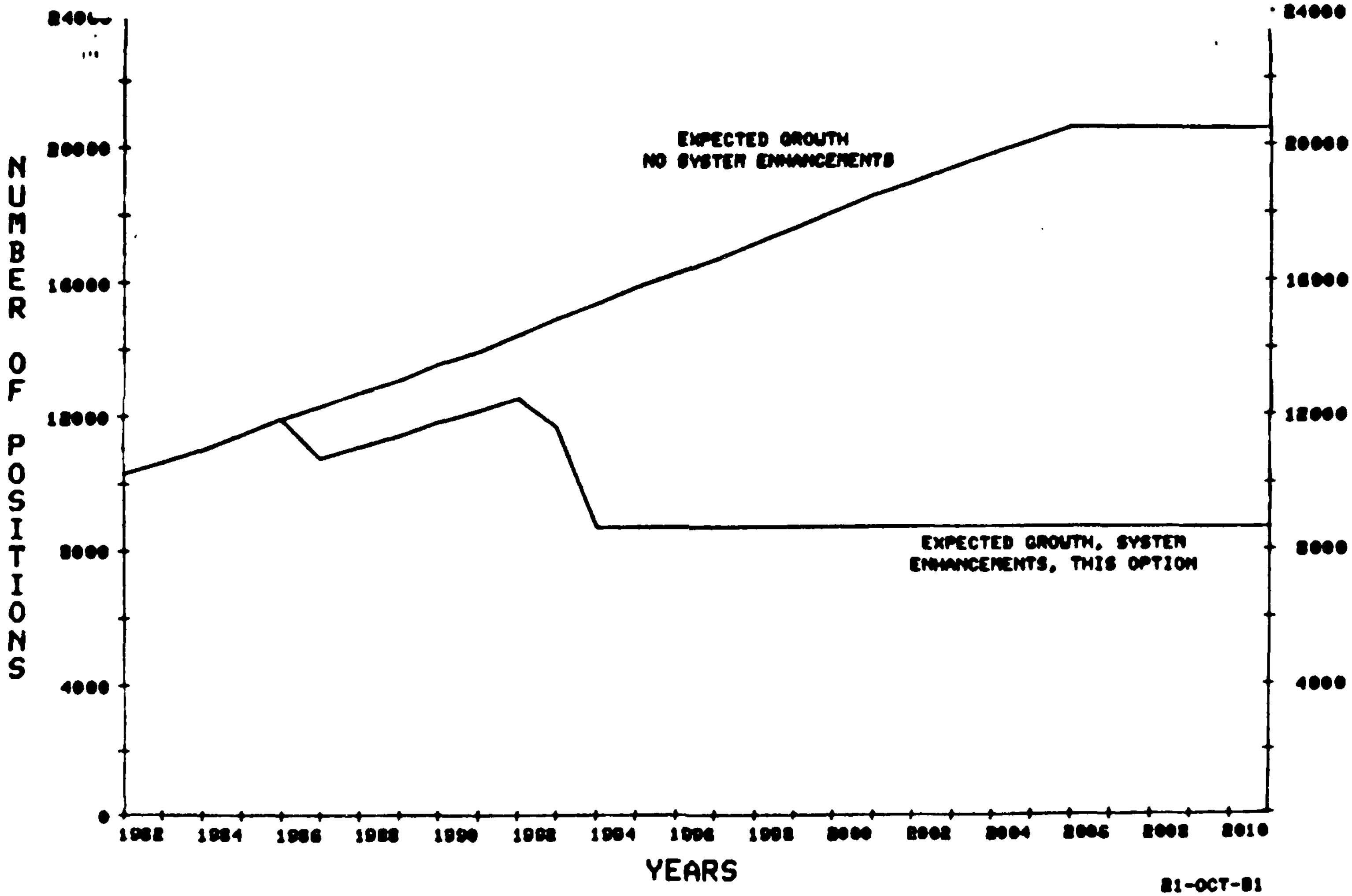

Figure 17. Benefit Category: Controller Productivity
Annual Controller Work Force Savings Projection in Positions
(7c) Replacement 5-2-1-1 vs. Basic

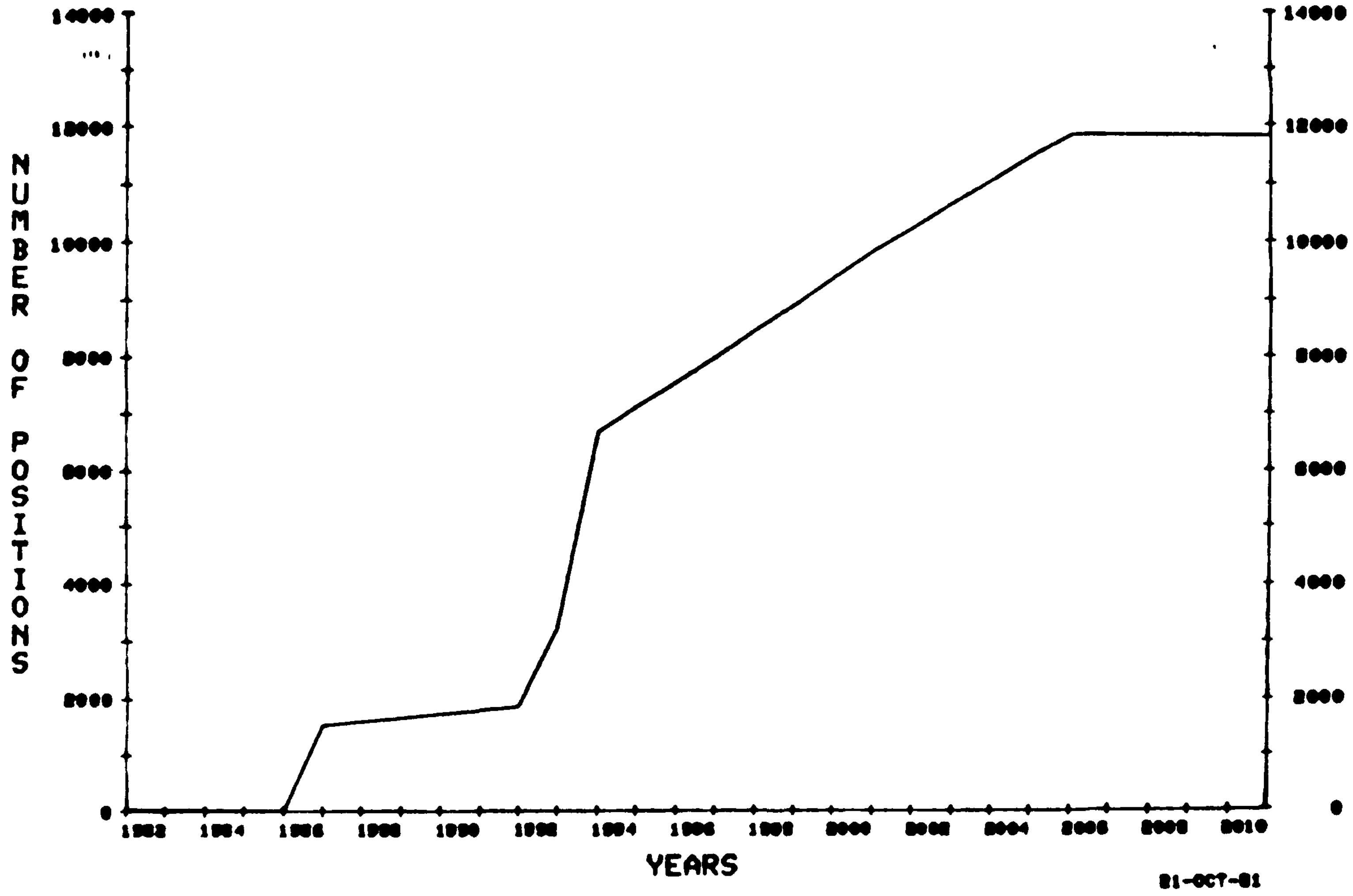

Figure 18. Benefit Category: Controller Productivity
Controller Work Force Savings Table
(7c) Replacement 5-2-1-1 vs. Basic

1. ESTIMATED ANNUAL IFR AIRCRAFT HANDLED GROWTH OF 3.10%
2. CONTROLLED WORK FORCE PEAKS IN 1992.
3. DISCOUNTED 10.0% PER YEAR.

YEAR	IFR AIRCRAFT HANDLED (MILLIONS)	UNCONTROLLED WORK FORCE	CONTROLLED WORK FORCE	SAVED WORK FORCE	PRODUCTIVITY ADJUSTED SALARY (THOUSANDS)	SALARY SAVED (BILLIONS)	ECONOMIC FACTOR	DISCOUNTED SALARY SAVED (BILLIONS)
1982	30.2	10265	10265	0	41.767	0.000	1.000	0.000
1983	31.5	10631	10601	0	42.686	0.000	0.909	0.000
1984	32.8	10964	10964	0	43.625	0.000	0.826	0.000
1985	34.4	11415	11415	0	44.585	0.000	0.751	0.000
1986	36.2	11885	11885	0	45.566	0.000	0.683	0.000
1987	37.6	12275	10728	1547	46.568	0.072	0.621	0.045
1988	39.0	12667	11062	1605	47.592	0.076	0.564	0.043
1989	40.5	13064	11399	1665	48.640	0.081	0.513	0.042
1990	42.2	13535	11799	1736	49.710	0.086	0.467	0.040
1991	43.5	13904	12113	1791	50.803	0.091	0.424	0.039
1992	45.2	14359	12500	1859	51.921	0.097	0.386	0.037
1993	47.0	14862	11638	3224	53.063	0.171	0.350	0.060
1994	48.6	15312	8638	6674	54.231	0.362	0.319	0.115
1995	50.3	15762	8638	7124	55.424	0.395	0.290	0.114
1996	51.8	16187	8638	7549	56.643	0.428	0.263	0.113
1997	53.4	16610	8638	7972	57.889	0.461	0.239	0.110
1998	55.1	17086	8638	8448	59.163	0.500	0.218	0.109
1999	56.7	17510	8638	8872	60.464	0.536	0.198	0.106
2000	58.4	17987	8638	9349	61.794	0.578	0.180	0.104
2001	60.1	18465	8638	9827	63.154	0.621	0.164	0.101
2002	61.6	18862	8638	10224	64.543	0.660	0.149	0.098
2003	63.1	19285	8638	10647	65.963	0.702	0.135	0.095
2004	64.6	19682	8638	11044	67.414	0.745	0.123	0.091
2005	66.0	20080	8638	11442	68.898	0.788	0.112	0.088
2006	67.4	20451	8638	11813	70.413	0.832	0.102	0.084
2007	68.7	20451	8638	11813	71.962	0.850	0.092	0.078
2008	69.9	20451	8638	11813	73.546	0.869	0.084	0.073
2009	71.2	20451	8638	11813	75.164	0.888	0.076	0.068
2010	72.2	20451	8638	11813	76.817	0.907	0.069	0.063
2011	73.4	20451	8638	11813	78.507	0.927	0.063	0.058

CUMULATIVE DISCOUNTED SALARY SAVED= 1.976 BILLION DOLLARS

23-SEP-81

Figure 19. **Benefit Category: Avoidance of Capacity-Induced Delays**
Delay Savings Data Table
(7c) Replacement 5-2-1-1
(1981 Dollars)

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*                                                *
*   1.  SYSTEM SAVINGS BEGIN IN 1991             *
*   2.  DISCOUNTED (10.0% PER YEAR) 1982-2011    *
*                                                *
**************************************************
```

YEAR	DELAY SAVINGS (BILLIONS)	ECONOMIC FACTOR	DISCOUNTED DELAY SAVINGS
1982	0.000	1.000	0.000
1983	0.000	0.909	0.000
1984	0.000	0.826	0.000
1985	0.000	0.751	0.000
1986	0.000	0.683	0.000
1987	0.000	0.621	0.000
1988	0.000	0.564	0.000
1989	0.000	0.513	0.000
1990	0.000	0.467	0.000
1991	0.068	0.424	0.029
1992	0.109	0.386	0.042
1993	0.161	0.350	0.056
1994	0.204	0.319	0.065
1995	0.254	0.290	0.074
1996	0.306	0.263	0.081
1997	0.370	0.239	0.089
1998	0.449	0.218	0.098
1999	0.516	0.198	0.102
2000	0.587	0.180	0.106
2001	0.650	0.164	0.106
2002	0.704	0.149	0.105
2003	0.758	0.135	0.102
2004	0.813	0.123	0.100
2005	0.865	0.112	0.097
2006	0.915	0.102	0.093
2007	0.970	0.092	0.090
2008	1.021	0.084	0.086
2009	1.078	0.076	0.082
2010	1.130	0.069	0.078
2011	1.192	0.063	0.075

CUMULATIVE DISCOUNTED DELAY SAVINGS = 1.754 BILLION DOLLARS

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Figure 20. Benefit Category: Fuel Efficiency
Annual Fuel Consumption Projection in Gallons
(7c) Replacement 5-2-1-1 vs. Basic

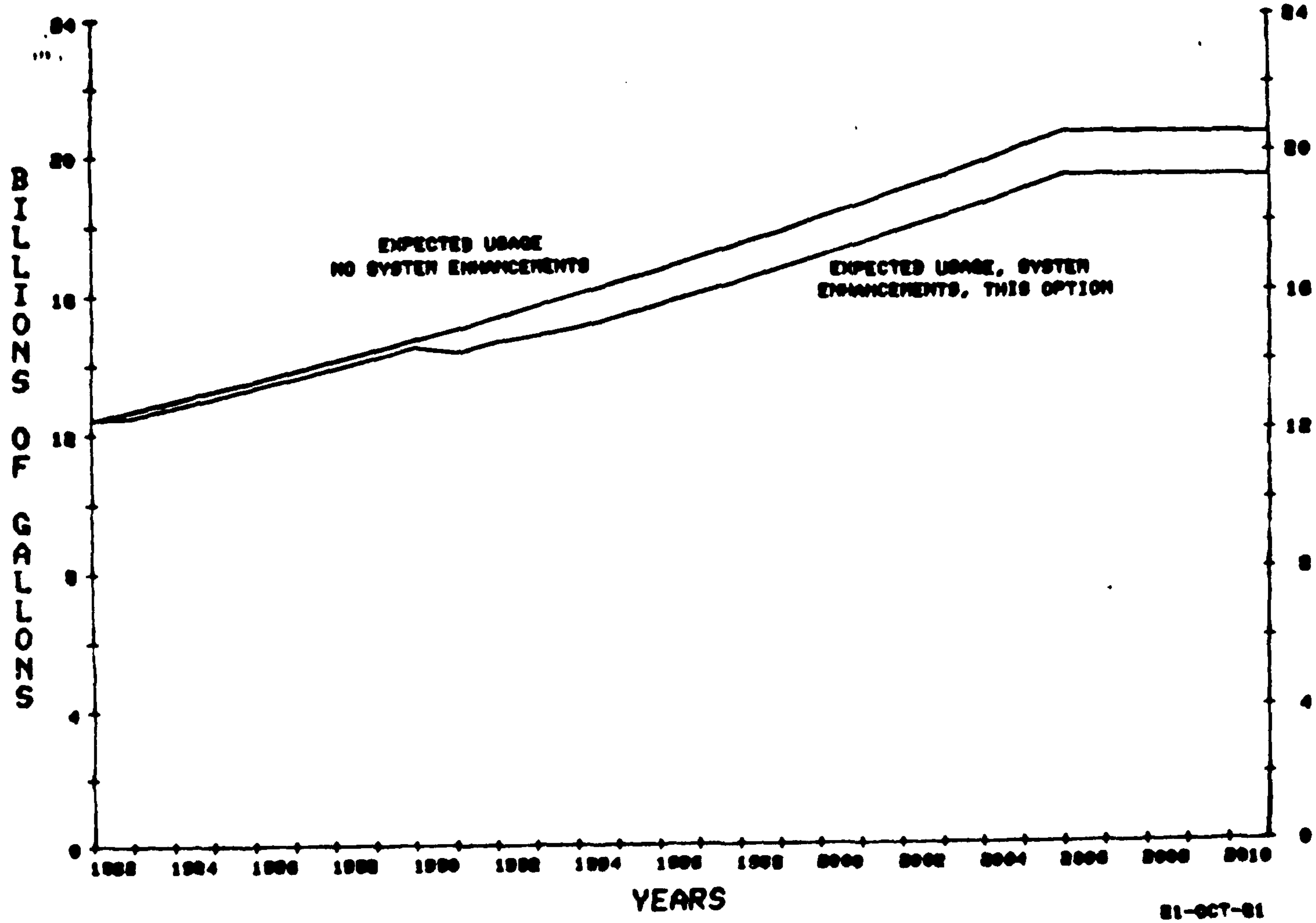

Figure 21. Benefit Category: Fuel Efficiency
Annual Fuel Savings Projection in Gallons
(7c) Replacement 5-2-1-1 vs. Basic

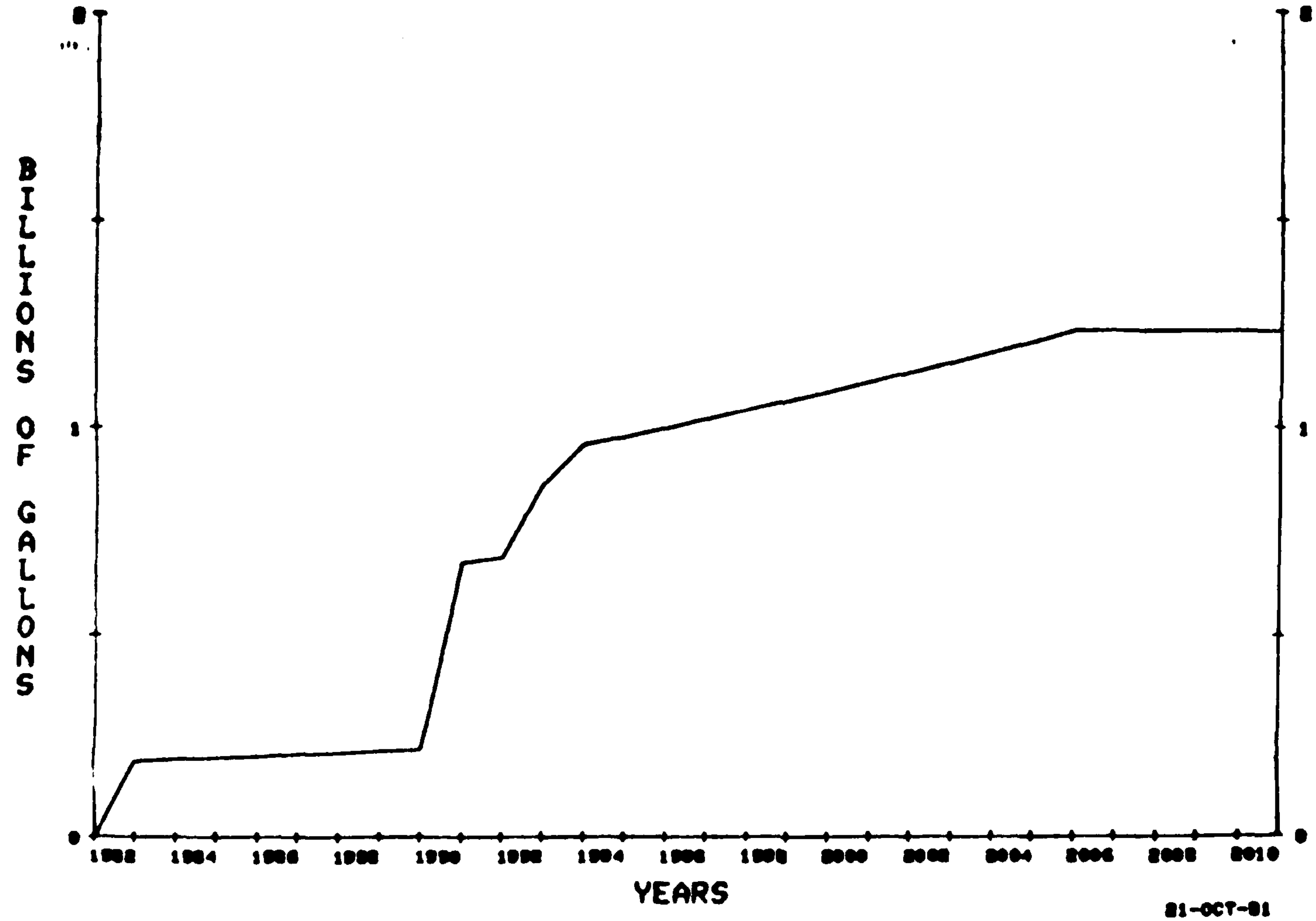

Figure 22. Benefit Category: Fuel Efficiency
Fuel Savings Table
(7c) Replacement 5-2-1-1 vs. Basic
(1981 Dollars)

1. ESTIMATED FUEL CONSUMPTION GROWTH RATE OF 2.10%
2. DISCOUNTED 10.0% PER YEAR

YEAR	TOTAL FUEL (BILLIONS OF GALLONS)	FUEL COST PER GALLON	TOTAL FUEL COST (BILLIONS)	SAVINGS FACTOR	SAVED FUEL COST (BILLIONS)	ECONOMIC FACTOR	DISCOUNTED FUEL SAVINGS (BILLIONS)
1982	12.410	1.00	12.410	0.000	0.000	1.000	0.000
1983	12.673	1.00	12.673	0.015	0.190	0.909	0.173
1984	12.941	1.00	12.941	0.015	0.194	0.826	0.160
1985	13.215	1.00	13.215	0.015	0.198	0.751	0.149
1986	13.494	1.00	13.494	0.015	0.202	0.683	0.138
1987	13.780	1.00	13.780	0.015	0.207	0.621	0.128
1988	14.071	1.00	14.071	0.015	0.211	0.564	0.119
1989	14.369	1.00	14.369	0.015	0.216	0.513	0.111
1990	14.673	1.00	14.673	0.015	0.220	0.467	0.103
1991	14.984	1.00	14.984	0.045	0.674	0.424	0.286
1992	15.301	1.00	15.301	0.045	0.689	0.386	0.265
1993	15.625	1.00	15.625	0.055	0.859	0.350	0.301
1994	15.955	1.00	15.955	0.060	0.957	0.319	0.305
1995	16.293	1.00	16.293	0.060	0.978	0.290	0.283
1996	16.638	1.00	16.638	0.060	0.998	0.263	0.263
1997	16.990	1.00	16.990	0.060	1.019	0.239	0.244
1998	17.349	1.00	17.349	0.060	1.041	0.218	0.227
1999	17.717	1.00	17.717	0.060	1.063	0.198	0.210
2000	18.092	1.00	18.092	0.060	1.085	0.180	0.195
2001	18.474	1.00	18.474	0.060	1.108	0.164	0.181
2002	18.865	1.00	18.865	0.060	1.132	0.149	0.168
2003	19.265	1.00	19.265	0.060	1.156	0.135	0.156
2004	19.672	1.00	19.672	0.060	1.180	0.123	0.145
2005	20.089	1.00	20.089	0.060	1.205	0.112	0.135
2006	20.514	1.00	20.514	0.060	1.231	0.102	0.125
2007	20.514	1.00	20.514	0.060	1.231	0.092	0.114
2008	20.514	1.00	20.514	0.060	1.231	0.084	0.103
2009	20.514	1.00	20.514	0.060	1.231	0.076	0.094
2010	20.514	1.00	20.514	0.060	1.231	0.069	0.085
2011	20.514	1.00	20.514	0.060	1.231	0.063	0.078

CUMULATIVE DISCOUNTED FUEL SAVINGS = 5.045 BILLION DOLLARS

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Figure 23. Benefit Category: Decreased Center Maintenance Costs
Annual Maintenance Work Force Growth Projection in Positions
(7c) Replacement 5-2-1-1 vs. Basic

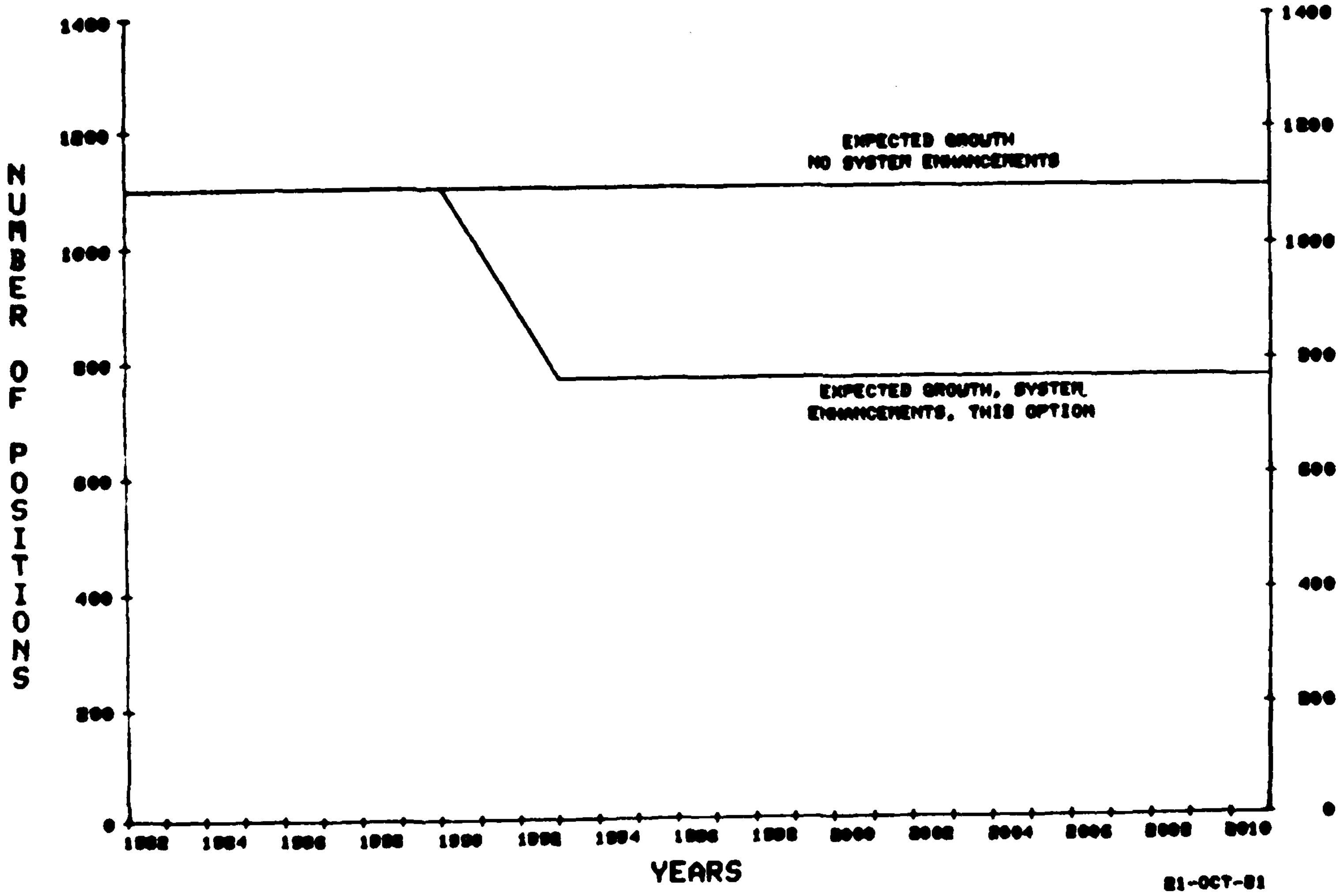

Figure 24. Benefit Category: Decreased Center Maintenance Costs
Annual Maintenance Work Force Savings Projection in Positions
(7c) Replacement 5-2-1-1 vs. Basic

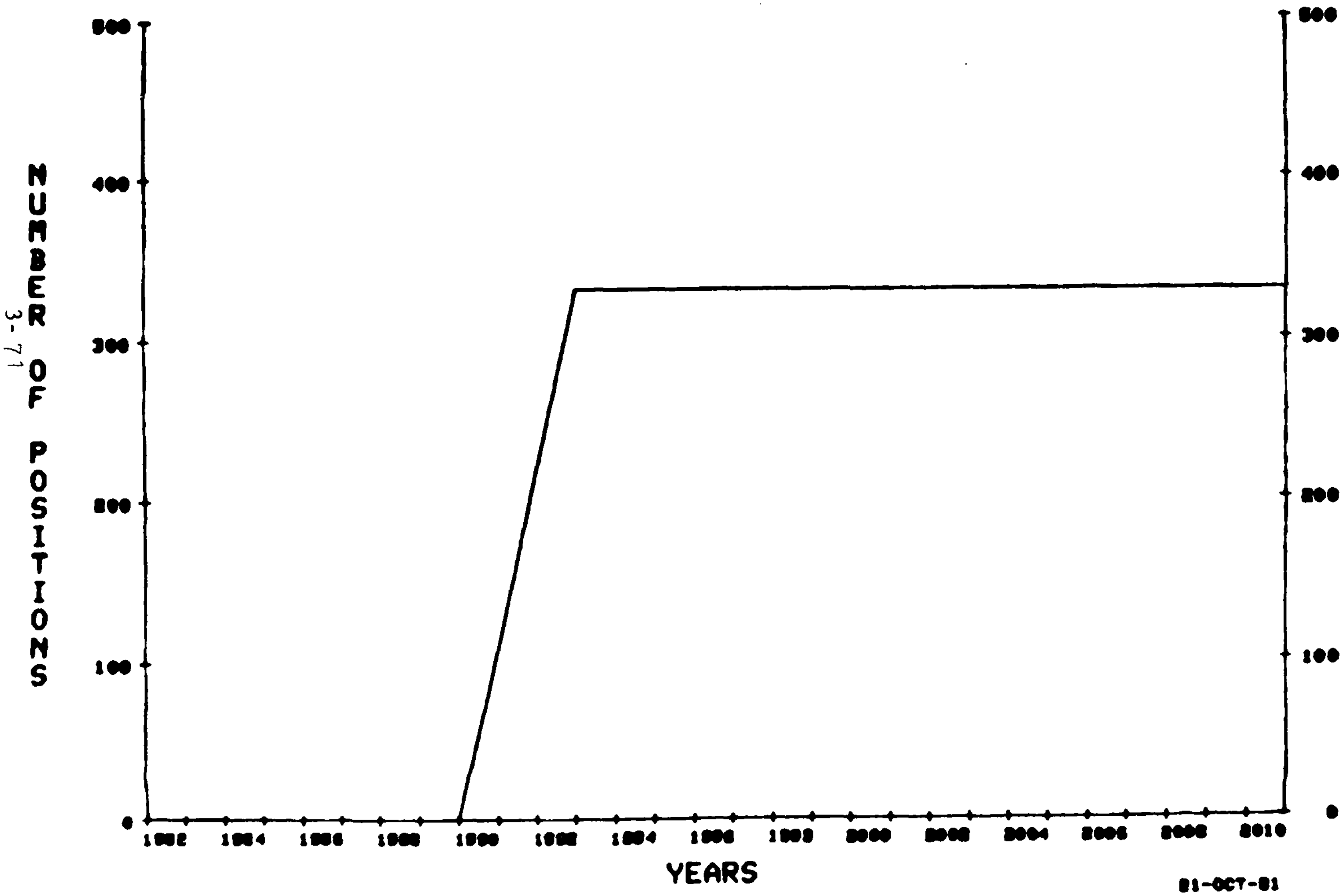

Figure 25. Benefit Category: Decreased Center Maintenance Costs
Maintenance Savings Table
(7c) Replacement 5-2-1-1 vs. Basic

1. SYSTEM SAVINGS BEGIN IN 1991
2. DISCOUNTED 10.0% PER YEAR, INFLATED 0.0% PER YEAR 1982-2011

YEAR	UNCONTROLLED WORK FORCE	CONTROLLED WORK FORCE	SAVED WORK FORCE	PRODUCTIVITY ADJ SALARY (THOUSANDS)	SALARY SAVED (BILLIONS)	ECONOMIC FACTOR	DISCOUNTED SALARY SAVED (BILLIONS)
1982	1100	1100	0	36.945	0.000	1.000	0.000
1983	1100	1100	0	37.758	0.000	0.909	0.000
1984	1100	1100	0	38.588	0.000	0.826	0.000
1985	1100	1100	0	39.437	0.000	0.751	0.000
1986	1100	1100	0	40.305	0.000	0.683	0.000
1987	1100	1100	0	41.192	0.000	0.621	0.000
1988	1100	1100	0	42.098	0.000	0.564	0.000
1989	1100	1100	0	43.024	0.000	0.513	0.000
1990	1100	1100	0	43.970	0.000	0.467	0.000
1991	1100	990	110	44.938	0.005	0.424	0.002
1992	1100	880	220	45.926	0.010	0.386	0.004
1993	1100	770	330	46.937	0.015	0.350	0.005
1994	1100	770	330	47.969	0.016	0.319	0.005
1995	1100	770	330	49.025	0.016	0.290	0.005
1996	1100	770	330	50.103	0.017	0.263	0.004
1997	1100	770	330	51.206	0.017	0.239	0.004
1998	1100	770	330	52.332	0.017	0.218	0.004
1999	1100	770	330	53.483	0.018	0.198	0.003
2000	1100	770	330	54.660	0.018	0.180	0.003
2001	1100	770	330	55.863	0.018	0.164	0.003
2002	1100	770	330	57.092	0.019	0.149	0.003
2003	1100	770	330	58.348	0.019	0.135	0.003
2004	1100	770	330	59.631	0.020	0.123	0.002
2005	1100	770	330	60.943	0.020	0.112	0.002
2006	1100	770	330	62.284	0.021	0.102	0.002
2007	1100	770	330	63.654	0.021	0.092	0.002
2008	1100	770	330	65.054	0.021	0.084	0.002
2009	1100	770	330	66.486	0.022	0.076	0.002
2010	1100	770	330	67.948	0.022	0.069	0.002
2011	1100	770	330	69.443	0.023	0.063	0.001

CUMULATIVE DISCOUNTED MAINTENANCE SAVINGS = 0.064 BILLION DOLLARS

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Figure 26. Cost Categories
Cost Data Table
(7c) Replacement 5-2-1-1 vs. Basic
(Billions of 1981 Dollars)

DISCOUNTED (10.0% PER YEAR) 1982-2011

YEAR	COMPUTER REPL. COSTS	MODE S-AVIONICS COSTS	MODE S-GROUND COSTS	OTHER 1/ COSTS	CLUSTER COSTS	ECONOMIC FACTOR	DISCOUNTED COSTS
1982	0.0173	0.0000	0.0000	0.0103	0.0276	1.000	0.0276
1983	0.0793	0.0000	0.0000	0.0379	0.1172	0.909	0.1065
1984	0.1005	0.0000	0.0000	0.0033	0.1038	0.826	0.0858
1985	0.0925	0.0463	0.0000	0.0026	0.1414	0.751	0.1062
1986	0.0702	0.0617	0.0399	0.1439	0.3157	0.683	0.2156
1987	0.0768	0.0610	0.0399	0.1369	0.3146	0.621	0.1953
1988	0.0902	0.0602	0.0399	0.0843	0.2746	0.584	0.1550
1989	0.1727	0.0263	0.0399	0.0500	0.2889	0.513	0.1483
1990	0.2995	0.0264	0.0399	0.0000	0.3658	0.467	0.1706
1991	0.2045	0.0270	0.0399	0.0000	0.2714	0.424	0.1151
1992	0.1101	0.0274	0.0000	0.0000	0.1375	0.386	0.0530
1993	0.0848	0.0276	0.0000	0.0000	0.1124	0.350	0.0394
1994	0.0045	0.0277	0.0000	0.0000	0.0322	0.319	0.0103
1995	0.0000	0.0138	0.0000	0.0000	0.0138	0.290	0.0040
1996	0.0000	0.0138	0.0000	0.0000	0.0138	0.263	0.0036
1997	0.0000	0.0138	0.0000	0.0000	0.0138	0.239	0.0033
1998	0.0000	0.0138	0.0000	0.0000	0.0138	0.218	0.0030
1999	0.0000	0.0138	0.0000	0.0000	0.0138	0.198	0.0027
2000	0.0000	0.0138	0.0000	0.0000	0.0138	0.180	0.0025
2001	0.0000	0.0138	0.0000	0.0000	0.0138	0.164	0.0023
2002	0.0000	0.0138	0.0000	0.0000	0.0138	0.149	0.0021
2003	0.0000	0.0138	0.0000	0.0000	0.0138	0.135	0.0019
2004	0.0000	0.0138	0.0000	0.0000	0.0138	0.123	0.0017
2005	0.0000	0.0138	0.0000	0.0000	0.0138	0.112	0.0015
2006	0.0000	0.0138	0.0000	0.0000	0.0138	0.102	0.0014
2007	0.0000	0.0138	0.0000	0.0000	0.0138	0.092	0.0013
2008	0.0000	0.0138	0.0000	0.0000	0.0138	0.084	0.0012
2009	0.0000	0.0138	0.0000	0.0000	0.0138	0.076	0.0011
2010	0.0000	0.0138	0.0000	0.0000	0.0138	0.069	0.0010
2011	0.0000	0.0138	0.0000	0.0000	0.0138	0.063	0.0009
TOTAL	1.4029	0.6262	0.2394	0.4692	2.7377		1.4641

1/ CA FOR VFR INTRUDER, CRA, ERM, ETABS, CWSU MODE S INTERFACE, TIDS

21-OCT-81

VI. An Alternative to the Benefit/Cost Method of Analysis An Analysis of the Methodology of Management to Objectives

In section II. B of this report, in which quantitative measures of the air traffic control system were discussed, it was stated that it is necessary for any system analysis which deals with performance levels which are multi-faceted, to assume some weighting scheme as a method for arriving at an overall measure of performance. It should be noted, that the quantifying of benefits and costs in dollar terms, an acceptable and typical method for combining different facets of performance, does, in fact, employ an implicit set of weighting factors. These weights depend, for example, on the study's estimates of the dollar costs "per minute saved" in estimating the benefits from the performance category: "reduced system delays." In the same way, had the study concluded that it was, indeed, possible to measure the differences in the "number of accidents averted" or the "numbers of lives saved" by implementing each of the investment options alternatively, the implicit weight or importance given to the performance category of safety would be determined by the dollar value estimated by the study for the saving of a life or the avoidance of an accident.

The essential point is that by choosing a method of analysis which measures benefits and costs in dollar terms, the study is imposing as implicit scheme for weighting the various facets of system performance that may not coincide with the decision-maker's own views of the relative importance of each of these facets. Thus, despite a study's effort to describe how dollars per unit of performance were estimated as a "worse case" or conservative assessment of a proposed program's potential, the manager faced with making an investment decision would, undoubtedly, prefer to assign his own weighting scheme to individual factors of performance. As a minimum, he would prefer knowing how a particular decision to invest depended on the study's assignment of dollar values.

For this reason, the study has chosen as an alternative to the calculation of dollar benefits and costs to present the various dimensions of ATC performance as individual "management objectives." The categories of objectives considered in the study are shown by the columnar headings in Table 10. The highest potential values in each category were estimated by referring to the separate analyses conducted in each performance category. These analyses are identified in Section VII, Listing of Supplementary Reports.

The study estimated that an investment alternative would rank higher in a performance category, if it were available at an earlier date. So, for example, the study has identified as an "objective," the savings of $1.8 billion due to the avoidance of delays caused by those capacity-limitation problems envisoned to occur during the 30 year planning horizon. Investment option 4, for example, is designed primarily to alleviate both current and future capacity-limitation problems. Hence, this option plus those which build upon it as a platform to fully-automated service are shown as achieving the highest objective rating of $1.8 billion.

However, none of the investment options are able to achieve in timely fashion the highest attainable objectives for: "reduced fuel," "decreased maintenance," or "increased controller productivity." The postponement

TABLE 10. RANKING OF INVESTMENT OPTIONS (DESCENDING ORDER)
BY MANAGEMENT OBJECTIVES
30 YEAR PLANNING HORIZON: 1982-2011

MANAGEMENT OBJECTIVES

I. Avoid Capacity $Delays		II. Reduce $Fuel		III. Decrease $Maintenance		IV. Increase Controller Productivity		I. THRU IV. Total Increase $Benefits		V. Reduced System Errors	
4A	$1.80	7B	$5.05	5	$0.07	8A	$1.98	7B	$8.84	7B	9000
4B	1.80	7C	5.05	8A	0.07	8B	1.98	7C	8.84	7C	9000
5	1.80	7A	4.85	8B	0.07	6	1.98	8A	8.70	8A	9000
8A	1.80	6	4.85	7A	0.06	7A	1.98	8B	8.70	8B	9000
8B	1.80	8A	4.85	7B	0.06	7B	1.98	7A	8.63	5	8000
2B	1.79	8B	4.85	7C	0.06	7C	1.98	6	8.56	6	8000
7B	1.75	5	4.77	4B	0.05	5	1.86	5	8.50	7A	8000
7C	1.75	2A	2.13	6	0.05	2A	0.71	4B	4.69	2A	3000
7A	1.73	2B	2.13	4A	0.04	2B	0.71	4A	4.68	2B	3000
6	1.68	3A	2.13	2A	0.00	3A	0.71	2B	4.63	3A	3000
2A	1.20	3B	2.13	2B	0.00	3B	0.71	2A	4.04	3B	3000
3A	0.91	4A	2.13	3A	0.00	4A	0.71	3A	3.75	4A	3000
3B	0.91	4B	2.13	3B	0.00	4B	0.71	3B	3.75	3B	3000
Max. Score	$1.80 (billion) discounted		$9.20 (billion) discounted		$0.15 (billion) discounted		$3.20 (billion) discounted		$14.35 (billion) discounted		11000 (system errors)

of the ability to achieve these objectives combined with the OMB prescribed method for discounting future benefits, result in the inability of any of the options to achieve the highest grade established for these categories.

The more important reason for identifying performance categories as "management objectives," is that it provides the opportunity to separately identify those essential factors which can not be quantified in dollar terms. It is all well and good, for example, to advise the reader that "Safety" has been excluded from the study's calculations of dollar benefits, and to warn against the tendency to regard those factors which can be measured as being more important when, clearly, they are not. To guard against this tendency, it is preferable to list "Safety" as a separate study objective. In this way, objectives expressed in dollar amounts can be compared--in relative ranking--to those expressed in non-monetary units. The manager faced with an investment decision can then apply his own weighting scheme--this time, an explicit one--to determine how sensitive his decision is to the scheme employed.

The investment options considered in the study are ranked in Table 10 according to those management objectives that were estimated as being attainable realistically.

It is important to note that the inclusion of "Safety" as an explicitly attainable objective does not alter the study's conclusions which were based previously on those factors which could be quantified in dollar terms:

The far term investment options capable of attaining full-automation are still preferred to the near term or interim-term solutions. This conclusion is only reinforced by the fact that the far term options achieve a higher grade in the "management objective" category of "Safety;" an estimated reduction of approximately 8500 system errors of the human variety out of a total potential reduction of about 11,000 errors. The near term or interim-term investments options were estimated to achieve reductions in system errors of a considerably lesser amount; a reduction of approximately 3000 system errors.

In addition, the study's over-all conclusion that no individual option is preferred among the far term options that were identified is, likewise, confirmed by this alternative presentation of an Analysis to Management Objectives.

VII. Listing of Supplementary Reports

A. "Automated Functional Improvements to the Current NAS System - Safety Benefits;" The MITRE Corporation, August 5, 1981

B. "The Estimating of Dollar Costs Due to Operational Delays;" AEM-100 Working Paper, August 1981

C. "Controller and Maintenance Workforce Savings," FAA Task Group 2 Working Paper, August 1981.

D. Rucker, R.A. "Estimates of the Fuel Savings Potential of Specific Functional Improvements to the Air Traffic Control System;" The MITRE Corporation July 20, 1981.

E. "Meeting En Route Air Traffic Control Requirements in the 1980's and 1990's -An Option Analysis: (see Appendix 2)

F. "Benefits, Cost Studies Methodology;" Seiler, Karl III, October 1981

END

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